SIR GERARD A. MUNTZ, BART.

PRESIDENT

THE INSTITUTE OF METALS

OFFICERS, 1910

President.

Sir GERARD A. MUNTZ, Bart., Birmingham.

Vice-Presidents.

JOHN D. BONNER	London.
Professor H. C. H. CARPENTER, M.A., Ph.D.	Manchester.
Professor W. GOWLAND, F.R.S.	London.
Professor A. K. HUNTINGTON, Assoc.R.S.M.	London.
Engineer Vice-Admiral H. J. ORAM, C.B.	London.
Sir HENRY A. WIGGIN, Bart.	Birmingham.

Members of Council.

T. A. BAYLISS	King's Norton.
G. A. BOEDDICKER	Birmingham.
CLIVE COOKSON	Newcastle-on-Tyne.
J. CORFIELD	Swansea.
R. KAYE GRAY	London.
SUMMERS HUNTER	North Shields.
R. S. HUTTON, D.Sc.	Sheffield.
E. MILLS	Swansea.
J. T. MILTON	London.
G. H. NISBETT	Preston.
E. RISTORI	London.
A. E. SEATON	London.
CECIL H. WILSON	Sheffield.
Professor T. TURNER, M.Sc., *Hon. Treasurer*	Birmingham.
WM. H. JOHNSON, B.Sc., *Hon. Secretary*	Manchester.

Hon. Auditor.

G. G. POPPLETON, C.A., Birmingham.

Secretary.

G. SHAW SCOTT, M.Sc.

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CORRIGENDA.

Vol. I. p. 193, line 22, *for* "areas" *read* "axes."

,, II. p. 87, line 18, *for* " Zinc, 32·20 per cent." *read* " Zinc, 35·20 per cent."

,, ., p. 278, line 42, *for* " F. S. Willott" *read* "F. J. Willott."

,, ., p. 324, line 3, *for* "kilowatts" *read* "watts."

THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING OF THE INSTITUTE OF METALS was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday and Wednesday, January 18 and 19, 1910, Sir WILLIAM H. WHITE, K.C.B., F.R.S., retiring President, occupying the chair on the first day, Tuesday, January 18, prior to the declaration of the result of the ballot for officers for the year 1910. Afterwards, and on Wednesday, January 19, the chair was occupied by Sir GERARD A. MUNTZ, Bart., President.

The SECRETARY read the minutes of the previous meeting held in Manchester on Thursday and Friday, October 14 and 15, 1909, which were found to be a correct record, and were signed by the Chairman.

The SECRETARY then read the following Report of Council upon the proceedings of the Institute during the year 1909 :—

REPORT OF COUNCIL.

In presenting to the members their Annual Report of the first complete year in the existence of the Institute of Metals, the Council are glad to state that the period has been one of considerable activity and progress.

A

The Roll of the Institute.

The numbers of members on the roll of the Institute at the commencement and end of the year were as follows :—

	Jan. 1, 1909.	Dec. 31, 1909.
Ordinary Members	355	505

Compared with the earliest stages of progress in the history of other technical institutions the rate of growth in membership is regarded as very satisfactory.

Finance.

From the Statement of Accounts for the year 1909 submitted to the members by the Honorary Treasurer, and verified by the Auditors, it will be observed that the total receipts amounted to £1107 13s. 7d. and the total expenditure to £866 13s. 11d.   The balance at the bank on December 31, 1909, was £751 19s. 8d., as compared with a balance of £430 10s. 1d. on December 31, 1908.

During the past year considerable non-recurring expenditure has had to be faced, notably in connection with the establishment of the new offices.   In these circumstances the Council regard the financial result of the first year's working as also a matter for congratulation.

Meetings.

During 1909 two meetings have been held.   The Annual General Meeting took place in London on January 19 and 20, when the following papers, which had been read at the Birmingham Meeting on November 11 and 12, 1908, were discussed :—

1. "On the Mechanism of Annealing in the case of certain Copper Alloys." By G. D. Bengough (Liverpool) and O. F. Hudson (Birmingham).
2. "On Inter-Metallic Compounds."   By Dr. Cecil H. Desch (Glasgow).
3. "On Aluminium and some of its Uses."   By J. T. W. Echevarri (London).
4. "On some Points of Interest concerning Copper and Copper Alloys."   By J. T. Milton (London).
5. "On Phosphor-Bronze."   By A. Philip (Portsmouth).
6. "On Plant used in the Manufacture of Tubes."   By W. H. A. Robertson (Bedford).
7. "On Metallographic Investigations of Alloys." By W. Rosenhain (London).

A paper on "The Relation between Science and Practice, and its Bearing on the Utility of the Institute of Metals," by Sir Gerard Muntz, Bart., was also read and discussed.

The Council desire to record their indebtedness to the Institution of Mechanical Engineers for the courtesy shown to the Institute of Metals in granting permission to hold the General Meeting and some meetings of the Council in their building at Storey's Gate, Westminster.

The Autumn Meeting was held at Manchester on October 14 and 15. Very complete arrangements were made by an influential Local Reception Committee, of which Dr. Carpenter was Chairman, and the meeting was most successful. The following papers were read and discussed on that occasion :—

1. "On the Constitution and Properties of the Ternary Alloys Aluminium-Copper-Tin." By J. H. ANDREW (Manchester) and C. A. EDWARDS (Manchester).

2. "On the Surface Appearance of Solders." By C. O. BANNISTER (London) and H. J. TABOR (London).

3. "On the Technical Assay of Zinc." By H. W. GREENWOOD (Liverpool) and Dr. F. J. BRISLEE (Liverpool).

4. "On Notes on the Production of Pure Spelter." By J. S. GLEN PRIMROSE (Glasgow).

5. "On Some Probable Causes of the Corrosion of Copper and Brass." By E. L. RHEAD (Manchester).

6. "On the Elastic Breakdown of Non-Ferrous Metals." By Professor C. A. SMITH (London).

7. "On the Copper-Zinc Alloys—A Study of Volume Changes during Solidification." By Professor T. TURNER (Birmingham) and M. T. MURRAY (Birmingham).

LIBRARY AND OFFICES.

For the first nine months of 1909 the offices of the Institute consisted of two rooms on the fifth floor at Caxton House, Westminster, S.W. Owing to the rapid development of the Institute, and the growth of correspondence and clerical work, it was felt by the Council that larger offices had become necessary. A convenient suite of offices was obtained on the second floor at Caxton House, in which there is provision for a Members' Room and Library, as well as for the secretarial staff. The Members' Room is comfortably furnished and provided with current technical literature, books of reference, &c. It is the desire of the Council that this room should be used by members for the purpose of reading, writing, and consulting books of reference, and it is hoped in course of time to establish a Library.

PUBLICATIONS.

The first volume of the Journal of the Institute was published in June, and was favourably received not only by members of the Institute, but by the technical Press and by allied Institutions. The following Institutions have already agreed to an interchange of Proceedings :—

Institution of Automobile Engineers.
    ,,   ,, Civil Engineers.
    ,,   ,, Electrical Engineers.
    ,,   ,, Mechanical Engineers.
    ,,   ,, Naval Architects.
Iron and Steel Institute.
Institute of Marine Engineers.
Junior Institution of Engineers.
The Chemical Society.
The Faraday Society.
West of Scotland Iron and Steel Institute.
Society of Chemical Industry.
American Electro-Chemical Society.
American Institute of Mining Engineers.
Department of Commerce and Labor, Bureau of Standards, Washington.
Königlichen Materialprüfungsamt, Berlin.
Staffordshire Iron and Steel Institute.

APPOINTMENT OF REPRESENTATIVES.

During the year the Institute has been invited to appoint representatives upon the Committee of the English Ceramic Society, and the Council have nominated Professor T. Turner, Mr. F. W. Harbord, and Mr. W. Murray Morrison. The Institute was also asked to send representatives to an International Congress of Mining, Metallurgy, Mechanics, and Geology, to be held at Düsseldorf in May 1910 ; Sir Gerard Muntz, Bart., and Professor Gowland have been nominated by the Council.

LOSSES BY DEATH.

During the year 1909 the Institute suffered the loss by death of two of its most distinguished members, in the persons of Norman Charles Cookson, a Vice-President, who died on May 15, 1909, and Francis Elgar, LL.D., F.R.S., who died on January 17, 1909.

The Honorary Treasurer, Professor T. TURNER, M.Sc., then read the following Report and Balance-sheet :—

TREASURER'S REPORT.

The previous report covered the first half year's work of the Institute ; that now submitted contains particulars of the first complete year. The year opened on January 1, 1909, with a balance in hand of £430 10s. 1d. ; at the end of the year this had risen to £751 19s. 8d., being an increase of £321 9s. 7d. The total receipts from ordinary subscriptions was £1107 13s. 7d., and the expenditure £866 13s. 11d. It may be explained that the odd sum received from subscriptions, which are all due in guineas, arises from small variations in the exchange of foreign payments. The item for furniture and fittings is naturally high, as the new offices and members' room have involved expenditure which will not generally occur. On the other hand, the Institute has to provide, from the balance in hand, the working expenses of half a year. In future also two larger volumes of the Journal will be issued annually, instead of one volume as in the present year. Rent and office expenses will be heavier with larger premises and the increased membership ; while incorporation will involve special expenditure in the immediate future. Towards this additional expenditure may, however, be set the proceeds of ninety-four subscriptions which are still outstanding.

The Institute is therefore to be heartily congratulated on its financial position, but now that under our retiring first President and Council the work has been so happily begun, care will be required on the part of their successors in order to maintain, or even improve upon, the present very satisfactory condition.

THOMAS TURNER.

January 18, 1910.

INSTITUTE OF METALS.

TREASURER'S ACCOUNT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDING DECEMBER 31, 1909.

RECEIPTS.

			£	s.	d.
Balance brought forward from last Account—					
Cash at Lloyd's Bank, Ltd..	£421	9	10		
Cash in hand of Secretary .	8	5	4		
„ „ Treasurer .	0	14	11		
			£430	10	1
Ordinary Subscriptions @ £2 2s. 0d.			1094	0	7
Students' Subscriptions @ £1 1s. 0d.			13	13	0
Special Subscriptions			42	1	0
Sales of Journal			11	16	7
Interest on Deposit Account			7	2	4
Sale of London Office Fittings			19	10	0
			£1618	13	7

PAYMENTS.

			£	s.	d.
Office Furniture and Fittings . . .			£180	14	9
Expenses of London and Manchester Meetings .			52	16	6
Expenses of Printing and Despatching Journal .			138	17	7
MANAGEMENT EXPENSES—					
Secretary's Salary . .	£200	0	0		
Rent, Rates, &c.. .	64	11	8		
Printing and Stationery .	75	11	10		
Clerical Assistance . .	69	15	5		
Postage, Travelling, and Sundries	84	6	2		
			494	5	1
Balance carried forward—					
Lloyd's Bank, Ltd.					
Deposit Account . .	£507	2	4		
General „ .	242	12	0		
Cash in hand of Secretary .	1	4	7		
„ „ Treasurer .	1	0	9		
			751	19	8
			£1618	13	7

I certify that I have audited the Accounts of the Institute for the year ending December 31, 1909, and in my opinion the above is a correct statement of the Receipts and Payments.

G. G. POPPLETON
(POPPLETON AND APPLEBY),
CHARTERED ACCOUNTANT,
BIRMINGHAM, LONDON, AND SHEFFIELD.
(*Honorary Auditor.*)

January 10, 1910.

Professor T. TURNER, M.Sc., Honorary Treasurer, in presenting his report, said that a little more than a year ago he was anxious that the Institute should raise its annual subscription to the sum of £600, as he thought that amount was necessary if any useful work was to be done. He was happy to say that the subscriptions had been raised to over £1100. He thought that some of the outstanding subscriptions would be lost, certain persons who had given in their names when the Institute was originally formed not having paid or taken any further interest in the work, and those names would have to be removed from the list. He believed, however, that the greater part of the subscriptions were thoroughly good.

The retiring PRESIDENT, in moving the adoption of the report and statement of accounts, said that before formally proposing the adoption of these he would say a word or two in explanation of certain points arising therefrom. The second volume of the proceedings of the Institute, the Journal, would be published in a few weeks, and he had no doubt it would be found in every way a worthy successor to the first, because it would contain a new feature, abstracts of papers published elsewhere on the subjects with which the Institute was concerned. With regard to the financial position, it looked better than it really was, and he desired to repeat the warning that the Treasurer had just given. The second volume of the Journal was completed, but not yet paid for. On the other hand, he trusted there would be an increase of members in the coming year—in fact, he had no doubt about it—so that larger receipts might be looked for. He moved, "That the Reports of the Council and of the Treasurer be received and adopted."

The motion was carried unanimously.

INCORPORATION OF THE INSTITUTE.

The retiring PRESIDENT said that the Council, as was explained at Manchester, was anxious to put the legal status of

the Institution on a secure footing. After full consideration it was decided that incorporation was the better course. At Manchester the members were informed that the steps necessary to secure that result were under the consideration of the Council, acting, of course, under legal advice. The Memorandum and Articles of Association and the necessary documents had since been prepared and circulated to the members. Before a motion was made asking the members to formally approve the action of the Council, it was thought proper to give an opportunity to any member present who might desire information or wish to make any further suggestions to do so. The document was in the hands of the members, and probably had been read ; it was not a very attractive piece of literature, but was a very useful one, and had involved great care and thought on the part of the Council. If, however, there was any amendment or improvement which any member wished to suggest, now was the time to do so.

No member rising to make any proposal, Sir WILLIAM WHITE said it might be considered there was no objection to the resolution, and he, therefore, formally moved on behalf of the Council, " That the Institute be incorporated under the Companies (Consolidation) Act, 1908, as a company limited by guarantee, and that application be made to the Board of Trade for a licence for the Institute to be registered as a company with limited liability without the addition of the word " limited " to its name, and that Sir Gerard Muntz, Bart., and Mr. A. E. Seaton be appointed to confer with the Secretary and Solicitor of the Institute to settle finally the Memorandum and Articles of Association, the draft of which has already been prepared."

Sir GERARD MUNTZ, Bart., said that he had very much pleasure in seconding the resolution. He thought it was most desirable that the Institute should be incorporated, but believed it was not necessary to add anything to what Sir William White had said.

The resolution was carried unanimously.

BALLOT FOR COUNCIL FOR 1910.

The retiring PRESIDENT said, with regard to the ballot for the election of President and Council for 1910, that the scrutineers appointed for that purpose had sealed the ballot box, into which the ballot papers were put as they were received. They had subsequently broken the seal and counted the ballot papers. Their report showed the Council for 1910 to be constituted as follows :—

President.

Sir GERARD A. MUNTZ, Bart.

Vice-Presidents.

Mr. J. D. BONNER	London.
Professor H. C. H. CARPENTER, M.A., Ph.D. .	Manchester.
Professor GOWLAND, F.R.S.	London.
Professor A. K. HUNTINGTON, Assoc.R.S.M. .	London.
Engineer Vice-Admiral H. J. ORAM, C.B. .	London.
Sir HENRY A. WIGGIN, Bart.	Birmingham.

Members of Council.

Mr. T. A. BAYLISS	Birmingham.
Mr. G. A. BOEDDICKER	Birmingham.
Mr. CLIVE COOKSON	Newcastle-on-Tyne.
Mr. J. CORFIELD	Swansea.
Mr. R. KAYE GRAY	London.
Mr. SUMMERS HUNTER	North Shields.
Dr. R. S. HUTTON, D.Sc.	Sheffield.
Mr. E. MILLS	Swansea.
Mr. J. T. MILTON	London.
Mr. G. H. NISBETT	Prescot.
Mr. E. RISTORI	London.
Mr. A. E. SEATON	London.
Mr. CECIL H. WILSON	Sheffield.
Professor T. TURNER, M.Sc., *Hon. Treasurer* .	Birmingham.
Mr. W. H. JOHNSON, B.Sc., *Hon. Secretary* . .	Manchester.

Sir WILLIAM WHITE observed that the number of ballot papers received, having regard to its proportion to the total membership, was unusually large, and compared well with the corresponding number for any technical society. On behalf of the Council he thanked the members sincerely for their

unanimous approval of the nominations the Council had made after great consideration. He congratulated the Institute on the advent of Sir Gerard Muntz to the chair, because no man by descent, occupation, and knowledge was better fitted to occupy the place of President of the Institute.

Election of Members.

The retiring President said the scrutineers declared the following gentlemen to have been duly elected members of the Institute; the number of members added was twelve, and the Institute was moving steadily forward.

The Secretary read the following list of names of candidates who had been duly elected members of the Institute :—

Name.	Address.	Qualification.	Proposers.
Chatterton, Alfred .	10 Mundania Road, Honor Oak, S.E.	Director of Industries	J. Echevarri. W. Mills. W. M. Morrison.
Enthoven, Henry John	153 Leadenhall Street, E.C.	Lead Smelter and Refiner	Sir H. A. Wiggin, Bart. J. G. Brockbank. G. A. Boeddicker.
Girdwood, Robert W.	Ivy Park Road, Ranmoor, Sheffield	Manager	W. R. Barclay. A. McWilliam. J. H. Wilson.
Haddock, Walter Thorpe	Endcliffe Close, Sheffield	Director of Heeley Silver and Wire Mills, Ltd.	C. H. Wilson. W. R. Barclay. R. J. Brown.
Jackson, Sydney Albert	Parsonage Road, Heaton Moor, Manchester	Engineer	B. S. Harlow. E. L. Rhead. S. Evans.
Parry, Laurence, Assoc. R.S.M.	22 Southwark Bridge Road, S.E.	Assayer and Metallurgical Chemist	H. J. Humphries. W. E. Watson. W. H. Merrett.
Paterson, David .	15/17 St. Simon Street, Salford, Manchester	Metal Merchant and Refiner	W. Paterson. J. Paterson. D. M'Phail.
Paterson, James .	15/17 St. Simon Street, Salford, Manchester	Metal Refiner	J. Paterson. D. M'Phail. W. Paterson.
Quack, E. Aitken .	Smith's Dock Co. Ltd., So. Shields	Manager of Brassfoundry, &c.	A. Laing. J. Bain. W. MacKenzie.
Ronald, Henry .	Eley Bros., Ltd., Angel Road, Edmonton, N.	Chief Supt., Eley Brothers	R. F. Hartley. H. B. Weeks. H. W. Keiffenheim.
Sperry, Erwin S. .	260 John Street, Bridgeport, Conn., U.S.A.	Editor, *The Brass World*	G. H. Clamer. W. R. Webster. C. H. Wilson.
Wilson, Anthony .	Braithwaite, Keswick	Mining Engineer	J. Corfield. R. W. G. Corfield. C. H. Eden.

VOTE OF THANKS TO SCRUTINEERS.

The retiring PRESIDENT moved a vote of thanks to the scrutineers for their services, which was carried unanimously.

He also moved that the best thanks of the Institute be given to the Hon. Secretary for his most valuable services to the Institute in that capacity since its beginning, and the resolution was unanimously carried.

The retiring PRESIDENT said there was one other matter which would interest the Institute. He had never failed, at every meeting of the Institute, to congratulate the members on their good fortune in securing as their Secretary Mr. Shaw Scott. He spoke from intimate personal knowledge, having been associated with Mr. Scott from the first, and he was convinced that the members could not have hoped to secure a more devoted or a better qualified servant of the Institute. The Council that day had been considering many aspects of the business of the Institute, and the members would certainly agree with the Council in the decision reached, that in appreciation of the services of the Secretary to the Institute there should be an increase of the salary paid to him. It had been necessary at the outset, when the finances were in an infantile condition, to proceed with caution and not to launch out into a rate of expenditure which could not be continued. That stage was now passed, and although care was still needed in dealing with finance, the Council felt that it was safe as well as proper to recognise more adequately the very valuable services of the Secretary. That was his last word as President, except to ask his friend and successor, Sir Gerard Muntz, to take the chair as President.

Sir WILLIAM WHITE then vacated the chair, which was taken by Sir Gerard Muntz, Bart., amidst cheering.

The PRESIDENT thanked the members very much for the honour they had done him in placing him in the position of President. His first duty was a very pleasing one, namely, to call upon Mr. Johnson to move a vote of thanks to the late President, Sir William White.

VOTE OF THANKS TO SIR WILLIAM WHITE.

Mr. W. H. JOHNSON said he had very great pleasure in proposing a vote of thanks, in which the members, he was sure, would all cordially join, to Sir William White for his able Presidency of the Institute, not only in the last year but from its commencement. Rather less than two years ago Dr. Carpenter and he waited on Sir William White at his office in Westminster, just an hour before the first meeting was held at the Institution of Mechanical Engineers, and begged him to preside over the meeting, assuring him that if he would do so the success of the Institute was assured. Contrary to his doctor's advice and that of his friends he consented to be the first President, and he had directed the Institute in a marvellous manner. Sir William had attended every meeting, and always arrived to the minute. He knew exactly what to do on every occasion, and he did it in the best possible manner. The wonderful success that had just been recorded in the Reports of the Council and the Treasurer was due in the main to Sir William White, and he therefore had the greatest pleasure in proposing, "That the best thanks of this meeting be accorded to Sir William White for his Presidency of the Institute."

Mr. A. PHILIP, in seconding the motion, said that on an occasion such as the present he envied Sir William White his gift of a golden tongue. Did he, the speaker, possess such a gift, it would be fully occupied that day in expressing their unanimous praises of the virtues of their departing President. It always seemed to him that there was something about votes of thanks to retiring officers which perhaps smacked somewhat of the funeral oration, but the idea of the words which some one had used on such an occasion, "I come to bury Cæsar, not to praise him," must fortunately be modified that day to words of praise alone. Whilst they welcomed the coming, they wished above all to speed the parting guest. But Sir William White could more suitably be described as a host than a guest; he had been, and always would be, a host in himself. It gave him very great pleasure that it fell to his

lot to have the honour of seconding this vote of thanks to their first President for his able and sympathetic conduct of the affairs of their Institute.

Sir WILLIAM WHITE, in reply, said he was most grateful for the terms in which the vote of thanks had been proposed and for the manner in which it had been received. In that wonderful old Book, so much loved by the people, there was a passage which said, " Let not him that putteth on the armour rejoice like him who putteth it off." There was a great deal of satisfaction in thinking of those words when any one had got through a piece of work and hoped he had done it fairly well. He did not in the least want to discourage the incoming President by this observation; he was rather thinking of it from the side of the man who had got through his task. Some people were always wishing they could have their time over again, but he thought that was very false philosophy. It was wiser to make the best use of time while it was passing, and it was no use wishing a perfectly hopeless wish. All that he claimed was, that from the moment he accepted the invitation to be President of the Institute of Metals, and to do what he could to further its establishment and development, he had endeavoured to do his best. It had not been a light task; it had involved a great deal more work than he expected, but he did not propose to weary the members with details of that nature. Although he had ceased to be President, and gladly retired in favour of his successor, so getting quit of responsibility, his interest in the Institute of Metals would not cease with his retirement from the chair. He believed the Institute to be one that had a good reason for its existence. It had already proved by its work that this was true, and in the future would prove it still more. No one would be more delighted than he to see the future success of the Institute become much greater than that which had been attained in the year and a half since it was started in that room. He did not forget the pioneer work done by Mr. Johnson and his friends in Manchester, and by the men from Birmingham who joined them. The Institute owed everything to those gentlemen; they conceived the idea, they

broke the ground, overcame preliminary difficulties, and made the Institute possible. It did seem to him that already, not merely in its publications, but in the spirit which had been created by the existence of the Institute, the anticipation of its founders had been more than fulfilled. At Birmingham and at Manchester there had been conferences of men interested in various sides of metallurgy as users, makers, men of science, all working towards the common end of improving a great national industry. Perhaps the most remarkable result yet attained was the greater liberality displayed by metal manufacturers in giving information. When the founders met and talked about the possibility of establishing the Institute, the greatest objection raised by experienced men, and treated very seriously, was the difficulty of making processes known and giving access to their works to other gentlemen engaged in metal manufacture. At the very first meeting in Birmingham it was proved beyond a doubt that this kind of difficulty was much less formidable than had been anticipated. Many leading firms then gave free access to their works, and there was an Exhibition of cases of " Diseased Metals " that would never be forgotten. Most people would have said that those concerned in making those metals might have been anxious to hide the specimens away, but that was not the attitude taken. Instead of concealing anything, the makers said, " This is what has happened to us ; these are the difficulties to be faced ; how can we best overcome them ; in what way can we combine to prevent recurrence ? " At Manchester the same spirit was displayed. That in itself was a wonderful achievement, which could never have been accomplished but for the existence of the Institute. As years went on and the various classes of members came to know one another better they would trust one another more, and there would be a marvellous future of usefulness before the Institute which would amply justify the hopes of its founders. To have assisted in any way in bringing about such results as those would always be a memory that he should cherish.

The PRESIDENT then delivered his Presidential Address, at the conclusion of which

Professor W. GOWLAND, F.R.S., said that he had pleasure in rising to propose a hearty vote of thanks to Sir Gerard Muntz for his very able address, and for the excellent practical advice contained in it. The members all knew Sir Gerard Muntz well, and as good wine needed no bush, so good men needed no eulogy. He felt that no words of his could adequately express the qualifications which Sir Gerard had for the office of President. He congratulated the Institute on having such a man for its President, and thus being again fortunate in having the right man in the right place.

Mr. A. E. SEATON, in seconding the motion, said he did so heartily, because the name Muntz was associated with his very earliest knowledge of metallurgy. When he was a very small boy his father, who was a shipowner, used to speak a great deal about the merits of the Muntz metal *versus* copper for ships' bottoms, and he used to wonder what the wonderful stuff was that he heard so much talk about. It might be, as the poet said, that there was nothing in a name, but it was somewhat curious that the names of the two first Presidents of the Institute should be so intimately associated with the non-ferrous metals. The name of Muntz, of course, was so well known in the non-ferrous metal trade of the United Kingdom, nay, of the world, that there was not much to be said further, except that that metal was the origin of the now favourite zinc bronzes, as it was really out of the original Muntz metal that those very valuable modern alloys sprang. Later on in his life he became acquainted with another set of metals which were known as "white" metals. Those, too, were of great importance to engineers; and it was the ambition of manufacturers of non-ferrous metals to produce a white metal that was as good if not better than that of his competitors' make and adorn it with an attractive name, and sell it at a high price—it was fatal to ask a low one. After all they were all white metals, and all more or less useful. He quite appreciated what Sir Gerard Muntz had said as to the difficulties under which he laboured in following such a President as Sir William White. He had known Sir William White now for forty years, and thought

he might say he knew him thoroughly; one of the last things he should choose to do would be to follow in the wake of Sir William, as there would be no hope of shining in the least. But Sir Gerard Muntz had given good proof that morning that he could shine on his own account, for he had furnished the Institute with an address which could be handed down from generation to generation as a book containing not only good advice and precepts worth following, but texts for future papers and many subjects for investigations. Therefore the thanks of the members were not only due to Sir Gerard for undertaking so very formidable a task as following Sir William White, but also for furnishing the Institute with such a very valuable address. There was one suggestion he wished to make, and that was, that the Institute might very well attach to itself a museum. Some years ago he began to collect samples of the curiosities of the non-ferrous metal world, but which were now scattered; he thought it was now possible, and desirable, for the Institute to start a small museum. He did not say it should be made as one simply of curiosities, but one that would afford very valuable instruction and useful for reference. It was of great value to be able to go and see what had happened to some particular alloy at some time or other under certain circumstances, and to compare with the discovery that a man perhaps himself had made.

The resolution was carried with acclamation.

The PRESIDENT, in returning thanks, thought some of the things that had been said were too flattering. He would try to do his best to carry out what had been suggested so far as his abilities permitted him, though he knew they were somewhat small for the job. He was, however, going to do the best he possibly could with them, and with the assistance of the Council it might be he might be able to do some useful work for the Institute. What Mr. Seaton had just suggested, a museum for the Institute, was a most desirable thing. If established by the Council, members who sent in samples should also send in a very full description

of the circumstances under which the samples were arrived at, the treatment, the cause of failure, and, as far as possible, the surrounding details. The great thing was to have investigations and knowledge of that sort put on record.

Papers were then read by Messrs. G. D. Bengough, M.A., and B. P. Hill, M.Sc. (Liverpool); Dr. Richard Seligman, Ph.Nat.D., and Mr. F. J. Willott (London); and Mr. Ernest A. Smith, Assoc.R.S.M. (Sheffield). Each paper was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the President, to the respective authors. The meeting then adjourned until 10 o'clock on Wednesday morning, January 19, 1910.

SECOND DAY'S PROCEEDINGS.

WEDNESDAY, *January* 19, 1910.

The second session of the Annual General Meeting was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on the morning of Wednesday, January 19, Sir Gerard A. Muntz, Bart., President, occupying the chair. Papers by Messrs. O. F. Hudson, M.Sc. (Birmingham), and E. F. Law, Assoc.R.S.M. (London); C. A. Klein (London); T. Vaughan Hughes, Assoc.R.S.M. (Birmingham); and C. O. Bannister, Assoc.R.S.M. (London), were read and discussed, a hearty vote of thanks being accorded in each case, on the motion of the President, to the respective authors.

CONCLUDING BUSINESS.

The PRESIDENT stated that owing to the lateness of the hour it was impossible to further continue the discussion. Several gentlemen had sent in their names to speak on the paper, and the Institute would be greatly obliged if they would send in their remarks in writing to the Secretary for incorporation in the Journal.

He desired to announce that a communication had been received from the Worshipful Company of Founders regarding

a competitive exhibition of foundry work to be held at the Ironmongers' Hall on the 7th and 8th of June next.   If those members who were interested in sending exhibits would apply to the Secretary, he would give them every information with regard to the matter.

It was now his great pleasure to move the following resolutions :—

> " Resolved, that the best thanks of the Institute be and are hereby tendered to the following :—
>
> (1) The Council of the Institution of Mechanical Engineers for their courtesy in permitting the use of their rooms on the occasion of this meeting.
> (2) The Deputy-Master of the Mint and other officials thereof for granting facilities to members of the Institute to visit the Royal Mint.
> (3) The Governors, Principal, and Staff of the Sir John Cass Institute for their reception of the members, and the opportunity afforded them of inspection of the buildings of the Institute and its educational equipment.
> (4) The Chief Superintendent of the Royal Arsenal and other officials thereof for granting facilities to members of the Institute to visit the Royal Arsenal at Woolwich.
> (5) The Directors of the Morgan Crucible Co. Ltd., who granted permission to the members of the Institute to visit their works."

He was sure the members were extremely obliged and grateful to the gentlemen mentioned in the resolution for all they had done for them, and it gave him great pleasure to propose the resolution.

Professor TURNER seconded the resolution, which he said he was sure the members would carry with acclamation.   The Council had made what had been to some extent an innovation for a London meeting in endeavouring to arrange for a number of visits, and he hoped the arrangement had been found agreeable to the members.   The Institute were very much indebted to the firms and to the authorities that had allowed the members to pay visits on the present occasion,

and they were specially indebted to the Institution in whose rooms they were at present met, which had always rendered them the greatest possible help.

The resolution was put and carried with acclamation.

Mr. W. H. JOHNSON said he had very much pleasure in proposing a vote of thanks to the able President of the Institute, Sir Gerard Muntz. Sir Gerard had had to succeed a very noted chairman in Sir William White, but he had satisfied the members' expectations in the very best manner, and they looked forward with great pleasure to his presiding over the Society. He felt that to have had a distinguished manufacturer for a second President was already putting the Institute of Metals on the very soundest footing. It would be remembered that the Institute was founded not merely for scientific study, but for the application of scientific discoveries to manufacture. The Institute had in its President a gentleman who was actively engaged day by day in the conduct of one of the largest non-ferrous metal works in the country and one of the most celebrated, and that was an assurance that the scientific side of the subject would be applied to manufacture. He had very much pleasure in proposing the vote of thanks.

Mr. A. E. SEATON, in seconding the motion, desired to re-echo all that Mr. Johnson had said with regard to Sir Gerard Muntz. From the beginning of the Institute down to the present moment they had been very fortunate in all their ways and all their doings, not least so in the choice of their first and their second President. If in the future such able men were selected to fill the chair as had occupied it up to the present time, the success of the Institute was bound to be very great. Without good leaders it was impossible to get good followers, and without good leaders institutions such as theirs very often drifted into mere social gatherings. In Sir Gerard Muntz the Institute possessed what might be called a high-class example of the Midland man, such men as made the city that he adorned no mean city in this kingdom.

It was impossible to find a more persevering class of people anywhere than in Birmingham. Although he was not a Birmingham man, he was very intimately associated with the city and visited it frequently; from that connection with Birmingham he derived additional pleasure in proposing the vote of thanks.

The resolution was put to the meeting by Mr. SEATON, and carried with acclamation.

The PRESIDENT, in reply, thanked Mr. Johnson, Mr. Seaton, and the members present for the very kind way in which the vote of thanks had been proposed and adopted. He would endeavour to live up to what Mr. Johnson had foreshadowed, and to support the reputation of the city from which he came. He had felt it a very high honour indeed to occupy the position of President of the Institute, and the members had been very patient with him in his conduct of the meeting. He was not so accustomed to such things as their previous President, Sir William White, was; it was a new job to him. The trouble he (the President) had during the meetings was that there was so much business to do that it was impossible to find time to do it all in; they had not suffered from not having enough to talk about, but from having too much to consider. For instance, that morning alone the discussion might have gone on for at least another hour, to the great advantage of all concerned.

The proceedings then terminated.

VISITS.

In the afternoon of January 18 visits were made by members to the Royal Mint, and to the Sir John Cass Technical Institute. The First Annual Dinner (a report of which is published on pp. 232–246) took place in the evening.

In the afternoon of January 19 visits were made by members to the Royal Woolwich Arsenal, and to the works of Messrs. The Morgan Crucible Company, Ltd.

THE DEVELOPMENT OF THE INSTITUTE OF METALS.

PRESIDENTIAL ADDRESS.

By Sir GERARD MUNTZ, Bart.

THIS being the first anniversary general meeting of the Institute, I think that the members may congratulate themselves upon the progress made by the Institute in the short time during which it has been in existence, and upon the rather remarkable quantity of valuable knowledge which has been contributed by members, in the shape of papers given at the three meetings which have so far taken place. If anything were needed to justify the founding of this, the infant of the Institutes, I think it has already been provided in the papers which have been read and are now embodied in our Journal.

To any one interested in the non-ferrous metals, there is much of value and interest in those papers, and they give promise of what, we may hope, will follow. If that promise be fulfilled, the Institute cannot fail to be of great utility to the world at large, and to workers in the non-ferrous metals in particular.

With regard to the number of members, there is certainly ground for congratulation, and in the quality of them there is an added element for gratification. In January 1909 there were 350 members of the Institute; to-day there are already 512, after only eighteen months' existence. Few associations of a similar nature can show such a record in so short a period. Our members embrace men of many parts and many attainments; those of tried experience, and younger men, who have yet their spurs to win. There is room for all. The knowledge accumulated by the elders is of great value as a basis for the foundation of a science of non-ferrous metals; to the younger members we look for fresh discoveries, and increased proficiency in their treatment. This Institute has

already begun to fulfil the hopes of its founders, and we, who are now part and parcel of its being, may look for far greater developments in the future. As yet we are rather on our trial, and have to prove our worth to the world at large. There is no reason why we should not attain to success, but it will need effort and some self-sacrifice on the part of all those who wish to make the Institute a real success and a lasting power. It appears to me that it should be our endeavour to make this Institute a centre of reference to all those interested in the subjects to which its scope extends.

In some other Institutes there have been established library funds, to which contributions may be made in the form of either books or money. I see no reason why we should not follow such an excellent lead.

Amongst our members are many who have written on matters of non-ferrous metallurgy before this Institute was founded. I am sure that we should be pleased to receive copies of those works, and place them on the shelves of our library. Others, who have not themselves been writers, may be possessors of volumes of interest, or, if not at present possessors, may yet become such, and feel inclined to endow our library with good books ; or, failing those circumstances, all members can subscribe to a library fund, leaving it to the Council to dispose of such funds in the manner they think most desirable. In a short time, under such conditions, there is no reason why we should not have a library well worthy the name, and one of infinite interest to our members. There must be a good many of us, who occasionally have a few hours in town which we do not quite know what to do with, to whom it would be pleasant to be able to spend idle moments in a library of which they were part-proprietors, studying those questions of metallurgy in which we are all interested.

All the knowledge, ancient or modern, bearing upon the treatment of non-ferrous metals needs collecting and codifying. Hitherto nothing serious has been done in that direction, and though there is already a large store of information both on the subject of the manufacture and usage of such metals, it is all scattered and uncoded, so that any one in search of it does not know where to turn for any information which may

be wanted. It behoves us to correct this evil, and supply a much-felt need. I look forward to the time when the Institute shall possess a library of reference which shall include all of value that has been, or may be, written on the subjects in which it is interested. There are already many valuable works in print on the nature and treatment of non-ferrous metals which would form a most excellent foundation for such a library. What is needed for its accumulation is money. At present the Institute cannot afford to launch out into large extravagances, but a small beginning has already been made in our library at Caxton House; the greater our success, the larger will become our list of members, and so the Institute will become more wealthy, and be able to do more; the more it can do, the faster it will grow, and the greater will be its success. There is much to be learnt from the past, as well as to be hoped for from the future.

We of the twentieth century sometimes flatter ourselves that we are a wonderful people, and that our science surpasses immeasurably that knowledge possessed by our forbears. But which of us to-day knows the secrets of the ancients of Egypt and Babylonia, which enabled them to harden bronzes to a cutting edge, and so face the stones for those marvels in architecture, the Pyramids and temples of Egypt?

There alone is a little matter which might occupy the scientific and practical members of this Institute very usefully for some time to come.

Another matter which is in great need of elucidation is the cause of corrosion of non-ferrous metals, especially copper and copper alloys, by sea-water; that is a cause of perpetual trouble to engineers and users of such metals, and one of constant anxiety and chagrin to manufacturers.

I should like to see the Institute undertake, in its corporate capacity, an investigation into that question, but that again means money, and I fear cannot yet be undertaken, unless by members individually; but, even if only in that form, an immense amount might be accomplished by members of our three grades—scientists, makers, and users—working together, and putting their heads together, to try to arrive at cause and effect; each helping the other by supplying all possible infor-

mation on the case in point. Until the Institute is in a position to establish a laboratory and research staff of its own, it must look to its members individually for the necessary help and research in any work which it desires to undertake. It must be some time yet before we are rich enough to think of such an establishment, but there is no harm in dreaming of the days which may be; and setting a high ideal is often a great aid to ultimate achievement. We have already made a small beginning, in the shape of a home of our own at Caxton House, where we have a members' room adjoining the Institute offices; there, it is hoped, members will make a practice of calling, so that it may become a meeting-place and centre of reunion.

Small beginnings often have great endings, and one must learn to walk before one can run; there is much ground for hope from our newly-started little home. If the Institute is to be an ultimate success, it must live up to its profession of faith better. In his Presidential address last year, Sir William White referred to these objects of the Institute under three clauses—(*a*), (*b*), and (*c*).*

(*a*) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures, excluding all questions connected with wages, management of works, and trades' regulations.

(*b*) To arrange periodical meetings for the purpose of discussing practical and scientific subjects bearing upon the manufacture, working, and use of the non-ferrous metals and their alloys.

(*c*) To advance the knowledge of metals and alloys, *e.g.* by the publication of a journal containing both original papers and abstracts of publications to these subjects, and in any other way.

Clause (*a*) is, regretfully, at present very much a dead letter; it needs bringing into force, and by some means or other putting into actual practice. In how many cases as yet have members of the Institute, as such, got into communication, with a view to elucidating any mystery or trouble which may have come under their notice in the course of their

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* *Journal of the Institute of Metals*, 1909, No. I. p. 45.

manufacture or usage of non-ferrous metals? Personally, I have only met with one such instance of importance, and that resulted in a very close research, and the accumulation of some valuable information.

What is most infinitely desirable is greater confidence and closer intercommunication between users and makers of non-ferrous metals, so that if anything goes wrong, or any difficult problems crop up, they may work together for its elucidation. A great deal can be done in that way, if only sufficient confidence can be established. As between makers, it is more difficult still to establish such confidence, and any interchange of ideas. It is but natural that between trade rivals there should be jealousy, and the desire to keep any special knowledge which has been obtained, often by long and arduous labour and research, is only human. But where there is not competition, and yet at the same time a common ground in the use of the same metals, for different purposes, we may hope for some friendly interchange of ideas; even in those more difficult cases, where there is trade jealousy, it is possible that a considerable amount of mutual good might result from a little more freedom in exchange. Possibly by-and-by, as the members of the Institute learn to know each other better, in the course of discussion on such papers as are brought before us, greater confidence and generosity may become apparent.

There is an infinite amount of information yet to be gathered in the production and treatment of metals—much that is yet a mystery to the cleverest scientist, and which the practical man could very usefully know. Those papers which we have already had read to us have opened up a good many side tracks, and shown the road to a very wide area of research, and I very much doubt whether this was previously apparent to the majority of our members. We must look to our scientific members to show us the road, then it will remain for the practical men to make use of the knowledge accumulated, and put it to its proper uses.

There are users, as well as makers, who could with advantage study the science of metals, with the properties peculiar to them. Makers are often too much wedded to old methods,

and steadfastly refuse to try anything new. Engineers are often apt to issue arbitrary specifications without, if I may be permitted to say so without offence, having sufficiently studied the peculiarities of the metal for which they are drawing up a specification : the result being, that the maker is given strange and weird tasks, and the user gets something which is altogether unsuited for the purpose for which it is required to be used. "A little knowledge is a dangerous thing"; it needs a lifetime of study to understand the peculiarities of even one metal under various conditions.

The multiplicity of alloys specified as manganese-bronze and gun-metal, and the variety of tests specified for them, is amusing. Mechanical tests are almost always given without any corresponding chemical tests, generally without even an analysis. Gun-metals, such as are supplied commonly, are often not gun-metals at all, but merely some form of brass. The tests specified would in themselves prevent gun-metal being supplied. Gun-metal is occasionally specified to stand forging hot. Now no true gun-metal will stand hot forging, so it becomes obvious that the makers must of necessity supply something different. Quite probably it is just as suitable for the purpose it is required for as gun-metal would be, but it is not gun-metal; its acceptance as such is only misleading to every one concerned. These are only cases in point. The chief matter is, that the general knowledge of the non-ferrous metals is simply appalling by its absence; it leaves the greater scope for the work of the Institute of Metals; there is much to learn, much already known which can be taught—better taught by such a body as the Institute than by any individual, or even by any university or school of metallurgy, because it would come with more weight from an Institute embracing so many different classes of thought, than from anywhere else.

I think we have cause to congratulate ourselves upon the quality of the papers which have been given at the several meetings of the Institute; so long as we are favoured with a continuity of work of such quality, I think we need have no anxiety as to the usefulness, or ultimate popularity and success, of this institution.

It would be pleasant to receive, perhaps, rather more encouragement and support from the practical makers; hitherto most of our contributions have come from the scientific or using branches. To make our efforts fully fruitful, we must induce all grades of our members to come forward and help to throw light on the different phases of the treatment and behaviour of the metals with which they come in contact.

I think that there is probably a larger field for investigation before this Institute than is open to any other kindred association to-day.

We have begun our accumulation of facts and knowledge in the first volume of our Journal. Contained in those few pages there is already a great amount of material of the highest interest, and any new discovery among the mysteries of metallurgy opens up long vistas of new research. I do not think that any one, who has to do with metals, could fail to find some points of interest in even our first volume, and I hope that many may be led to join us by having seen and read what is written therein.

So far the Institute has visited but two of our great manufacturing centres, and is only beginning to make itself known, and scarcely as yet felt, as a great power in the world. There are many more of our great cities and seaports to be visited, and it is more especially to the latter that, I think, we may look for recruits; from amongst those men who are constantly engaged in the use of non-ferrous metals in connection with our great shipbuilding industry, always running up against something in the nature of a puzzle as to the cause of some peculiarity in the behaviour, or the failure of some part of the machinery under their control. Hitherto they have had to depend chiefly on themselves, or on stray gleams of knowledge gathered at hazard, for the elucidation of their mysteries. What is needed is, that they should learn to look to the Institute of Metals to help them out of their troubles, and put them on the right road to avoid their repetition.

It would be a most desirable thing if a means could be arranged by which members could get into touch with each other, and correspond upon or meet to discuss matters of this nature. There seems to be no real difficulty about this. A

system might be initiated by which any member meeting with some obscure problem, upon which he desired light, might communicate it to the Secretary of the Institute; either with a request that he should be put into touch with such members as might be able to throw light upon it; or, better still, that there should be established a sort of monthly periodical of the Institute, for issue to all members who desired it, in which such matters might be dealt with. By the latter means every member could be put in touch with the latest development, and much good might be attained.

Clause (*b*) has, to a certain extent, been carried out at the general meetings of the Institute which have been held respectively in Birmingham, London, and Manchester; but between these general meetings there have been, and always must be, long periods of silence and inactivity, when members lose touch with each other, and interest slumbers. It would be an excellent thing if the spirit of interest and activity could be kept more actively alive during those periods: we know, of course, that some of our members are actively engaged in preparing papers for reading at the next general meeting which is approaching; doing excellent research work, and following up valuable clues which they may have got hold of; but it is not sufficient that only a few isolated men should be so engaged, whilst the bulk of our members are, so to speak, stagnating—to a large extent rusting for want of use, for the need of rubbing their brains against those of their fellows to brighten them up. A much more frequent intercourse is needed. Such could be obtained by the establishment of local centres in all the larger provincial cities, where there is a sufficiency of members to make it worth while, as well as in the Metropolis, where meetings could be more frequently held, and where matters of interest—which occur almost daily— might be brought forward and discussed. A great deal of useful information would thus be obtained, and material provided for the larger and more general field of discussion available at our general meetings, and in the pages of our Journal.

If local centres are established, they must be prepared to support themselves, and must not look to the parent society to bear their expenses: neither must they expect to have their

proceedings published in the Journal of the Institute. But, on the other hand, it is more than probable that the subjects which arise at the local meetings may be of such interest, that they can properly and advisedly be in some form or other presented again at the general meeting, and may form the basis for most interesting discussion.

If such local centres could be established, they would most likely do more than anything else could to bring together users and makers and scientists. Speaking as a manufacturer, I can say, without fear of contradiction from my fellows, that scarcely a day passes but that something of interest occurs with regard to the treatment of metals. As metal manufacturers, we have to be, as it were, "jacks of all trades," a little of metallurgist, a little of mechanician, a little of engineer, and, above all these things, men of business, understanding the cost of things, and the possibility of turning out our goods at a merchantable price, so that they can be practically employed by our customers. Very many things are possible with metals in the laboratory which are totally useless in practice, owing to the costliness of the process or materials, but occasionally such matters may be reduced to practical forms by modification; and if the manufacturer and the scientist worked together to the best advantage, doubtless more openings of that nature would occur. The manufacturer has but little time for research and experiments. His time is pretty fully occupied with matters of commerce, and he must either supply a special staff for research work, or look to others for the solving of his problems. Probably the ideal is for the manufacturer to be able to employ a regular staff of young men, tried in scientific research, who can devote their time to applying their knowledge to putting into practice such theories, improvements, and developments as may arise in the works where they are employed. But to begin with, they must have a sound scientific education, and it is to our great schools of science and our universities that we must look for such young men. Those of us who have visited the metallurgical departments of the Universities of Birmingham and Manchester during our respective meetings at those cities must have been struck, and, I think, agreeably surprised in many cases,

with the work which is being done in those institutions in the matter of scientific instruction in metallurgy.   It is work which is very well worth doing.   There is a large field for young metallurgists in non-ferrous work, and in these days of the overcrowding of our professions, a young man might do far worse than take up that line.   The Universities have recognised science at last, and honours are generally given for good work.   In our new articles of incorporation, our council has provided that we too shall give honours for good work done in the course of metallurgical research, and it is suggested that we confer fellowship of our Institute of Metals upon those who have in marked degree done good work towards forwarding our object; not necessarily in personal work of research, but in any shape or form which shall forward, or has forwarded, the good work which we have undertaken. I hope that the time may come, and not long hence, when that fellowship may be felt to be a high and distinguished addition to any honour which a man may already possess.   The incorporation of our Institute is in itself a great step forward; it must make us feel that we have become a solid body, and are no longer in the nebulous stage, and adds a dignity to the Institute to which we had not hitherto attained.

To revert to the three clauses earlier referred to, there remains clause (*c*).   I think we may consider that this, at least, has already been well established, and is on the road to being carried out in the spirit in which it was intended. Already two volumes of the Journal of the Institute are in print, containing most valuable material, well worth the perusal of any one practically interested in the metallurgy of non-ferrous metals.   The second volume is perhaps of even greater interest than the first, and to-day we shall have the pleasure of listening to more papers, and the consequent discussion thereupon, which will go to supply the material for a further volume.   It is proposed to publish two issues of our Journal per annum instead of publishing one large volume every year.   Thus the half-yearly volumes will not be too cumbrous for convenient use. Another point in favour of such a course is, that it will enable members to have the result of the proceedings in their hands sooner than if they were held back for publication only once a

year. I feel sure that we are, all of us, always anxious to receive our volumes, and to be able to refresh our memories on the subjects which we have heard discussed at our meetings, with the hope of finding added interest in the form of any comment on, or contribution to, the discussion which may have been received in writing after the close of the verbal discussion.

That our Journal is of interest has been shown by the considerable demand which there has already been for it. I am sure it will be a matter of self-congratulation to all of us to learn of the large number of kindred societies who have applied to us for copies of our Journal, and have arranged with us for an interchange of proceedings. Many of these societies deal with matters which are of great interest to ourselves, and it is pleasant to know that they think our proceedings of sufficient interest to cause them to ask for details of our work.

The work to which we have put our hands is no small one ; the field that lies before us is vast, and the knowledge we as yet have is but a drop in the ocean, but I feel that we have made a good start, and that there is good ground for hope for the success and usefulness of this our Institute in the future. We are the infant of the Institutes, and shall need much care and education before we attain to full maturity. One thing we may be very grateful for, that is the most kindly interest shown in our welfare by our elders amongst the Institutes. On all sides we have met with the greatest kindness and encouragement : help has been given us willingly when asked for; not least by that great Institution in whose house we are guests to-day : who have previously lent us their Hall for our meetings, and have allowed us to use this building for our council and committee meetings, from the beginning of our existence up to the time that we were able to establish a small beginning for ourselves at Caxton House. I am sure that we all feel most deeply grateful for the kindness they have shown us, and shall carry a memory of it with us, and hand it down to our successors in the Institute as a debt to be remembered, and a memory to be honoured.

In conclusion, I should like to express my very deep recognition of the honour the Institute of Metals has done me, in

selecting me to be its second President. It is difficult to me
to put my feelings on that subject into words. I feel that it
is a post which will need my best to fill with any sort of
success or credit. It is one carrying much responsibility—
more in these first days of our Institute, when it has yet to
make its way, than may be the case later on ; for it lies with
the near future whether we are to make our venture a success
or a failure. A mistake made now might mar all the good we
have so far done. When it was suggested to me that I should
take the office, I rather shied at the idea. It seemed too big
an undertaking, and I rather doubted, and I still fear, my
ability to carry it through as I should wish to. At any time,
and under any circumstances, I should have felt that ; but
added to my other difficulties, I felt that to follow such a man
as our first President, Sir William White, was almost courting
disaster. His experience in such matters has been extremely
wide, and enables him to handle such business with a facility
and *savoire faire* which but few men possess. The work he has
done for us has been something which we can never sufficiently
appreciate or recognise. I say without hesitation, that if we
had not had the help and guidance of Sir William White, we
should have been a very long way from where we now stand
in the matter of success. He has been a host in himself. His
presence in the chair at our meetings, and the genial and yet
business-like manner in which he has conducted our proceed-
ings, almost compelled success, encouraged us all to greater
efforts, made us put our shoulders to the wheel, and do our best
to help the coach along. His example acted as an incentive to
all the members of our Council, and they have vied with each
other, endeavouring to follow his lead, in doing everything
that could be done to insure the success of our work. Whatever
success we may attain to in the future, and whoever else may
follow in the Presidential chair, I am sure that the Institute
will ever look back gratefully to the good work our first
President did for it, and the kindly and generous help he
gave it in the hour of its greatest need.

I feel that in following such a man I am indeed making a
grave venture, but it was chiefly because it was Sir William's own
personal wish that I should undertake the task that I do so.

He required some one from amongst the manufacturers, and, for reasons best known to himself, thought I was the man he wanted.

Whatever other qualifications I feel I lack, I know that at least my heart will be in that work which you have honoured me by placing in my hands, and that everything which I am able to do to help the Institute forward to success will be done with all my heart and all my ability.

THE PROPERTIES AND CONSTITUTION OF COPPER-ARSENIC ALLOYS

By GUY D. BENGOUGH, M.A., AND B. P. HILL, M.Sc.,

RESPECTIVELY LECTURER IN METALLURGY AND RESEARCH STUDENT IN THE LIVERPOOL UNIVERSITY.

FOR convenience of reference the paper is divided up as follows :—

GENERAL INTRODUCTION.

Alloys of copper and arsenic containing but small percentages of arsenic are used in this country mainly for two purposes : (1) for locomotive parts, particularly for fire-boxes ; (2) for dynamo brushes.

The reasons for using an arsenic alloy instead of pure copper are, firstly, to secure greater strength and rigidity, particularly at high temperatures ; and, secondly, to secure an alloy that shall resist the action of flames—that is, of gases at high temperatures. The working properties of copper are not interfered with, at least to any great extent, by small quantities of arsenic, but the fact that even small percentages seriously lower its conductivity prevents the use of these alloys for electrical purposes.

Several workers have investigated this effect of arsenic on the conductivity of copper, and recently Hiorns and Lamb ([1]) have given an interesting curve (Fig. 1) showing its effect quantitatively. The authors therefore considered that no further work on this branch of the subject was necessary.

The proportion of arsenic that can be usefully employed for increasing the strength of copper has been generally con-
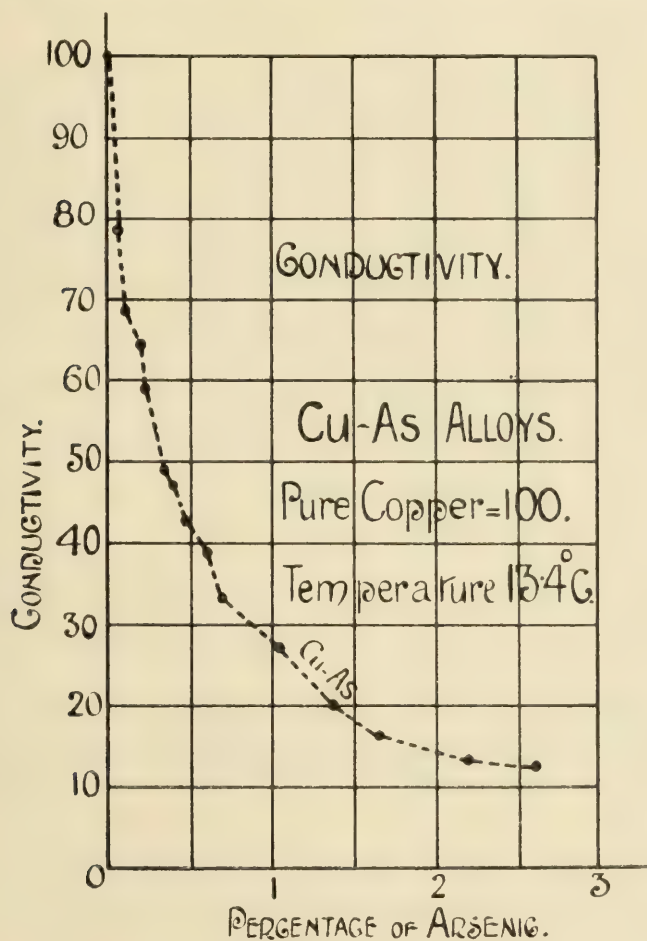
FIG. 1.—(Hiorns.)

sidered to be much less than 1 per cent., and it has been supposed that beyond this proportion the alloys tend to be brittle. Within the above limit as a maximum, however, very different opinions are held both by engineers and metallurgists. Platten ([2]) quotes the following as typical of the amounts of arsenic called for by various engineers :—

(*a*) Not to exceed 2 per cent.

(*b*) Must be present in proportions between 0·25 and 0·4 per cent.

(*c*) Must be present in proportions between 0·35 and 0·55 per cent.

(*d*) Must not be above 0·15 per cent.

Other engineers prefer to exclude arsenic altogether for all purposes, and call for "best select" copper, *i.e.* one of the purest forms of commercial copper, usually containing only traces of arsenic.

Lewis ([3]) has published some tests on the mechanical properties of arsenic alloys, but his results are not sufficiently numerous to provide a comprehensive study of this question. They are given in Table I. W. Stahl ([4]) has compared copper-arsenic and copper-nickel alloys containing small percentages of nickel or arsenic. He concludes that arsenic increases the tensile strength, malleability, and ductility, and prevents the absorption of gases when present in sufficient quantities. It also increases the true hardness and marks the harmful effect of bismuth. He considers that the alloys with from 0·3 to 0·35 per cent. are satisfactory, and gives their mechanical properties as—

Maximum stress	14 to 14·6 tons per square inch.
Elongation	33 to 44 per cent.
Contraction of area	47 to 62 per cent.

He considers it doubtful whether copper-arsenic alloys will stand considerable fluctuations of temperature and stress. His paper is a short one, and does not contain many experimental data.

In view of the small number of published experimental results one of the authors decided to investigate this matter in a more detailed manner, and, after consultation with Sir Gerard Muntz as a manufacturer of these alloys, sketched out a research which might reasonably be expected to throw some light on the following questions :—

(*a*) What is the best proportion of arsenic to use in these alloys ?

(*b*) What is the effect of heat treatment on them ?

(*c*) What is the effect of heating them in a reducing atmosphere ?

The authors would have liked to carry out, in addition, tests on these alloys at high temperatures, but unfortunately the apparatus at their disposal did not permit of this.

In accordance with the general principle that no research on the mechanical properties of alloys can be considered complete or conclusive without a knowledge of their constitution, they took this matter into consideration at an early stage of the work. On looking up the literature of the subject they found three important papers dealing with this matter. The first of these is by Hiorns ([5]), and deals only with the liquidus curve. The other two are by Friedrich ([6]), ([7]), who deals also with certain changes in the solid. His liquidus curve differs radically from Hiorns'; and in the second of his papers he discusses these differences, and rejects certain of Hiorns' conclusions. It seemed necessary, therefore, to discriminate between the two sets of results, and Part II. of the paper deals with this matter. Part I. contains only heat treatment and mechanical tests, with a discussion thereon.

TABLE I. (E. A. LEWIS).

Arsenic per Cent.	Maximum Stress. Tons per Square Inch.	Elongation per Cent.	Elastic Limit.
1·80	17·83	20	11·52
1·37	18·83	28	10·09
0·94	18·02	25	9·01
0·75	18·31	21	8·91
0·53	18·38	29·5	9·52
0·24	16·92	27·5	10·25
0·00	13·40	25	7·00

PART I.—MECHANICAL PROPERTIES OF THE ALLOYS.

SECTION A.—PREPARATION AND TABLES OF TESTS.

Material.—By the kindness of the President, Sir Gerard Muntz, the authors were supplied with a set of five hard

rolled bars of copper, containing amounts of arsenic given in the following table :—*

	Bar A.	Bar C.	Bar D.	Bar E.	Bar B.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Arsenic	0·04	0·26	0·75	0·94	1·94
Lead	nil	nil	nil	nil	nil
Tin	nil	nil	nil	nil	nil
Iron	nil	nil	nil	nil	nil
Sulphur	0·005	0·007	0·006	0·008	0·005
Copper (by difference) .	99·055	99·733	99·344	99·052	98·055

Nil means less than 0·005.

The bars were prepared from B E R copper and metallic arsenic. The latter was added to the molten copper in a crucible furnace. The resulting alloy was poled and poured into an iron ingot mould, giving a 3 inch round ingot, 3 feet long. The ingots were broken down at a good red heat, and finished with one reheating. They were drawn cold on a draw-bench in one pass of $\frac{3}{64}$ inch. One bar, containing 1·94 per cent. of arsenic, had to be rolled at a higher temperature than the others. It frequently slipped in the rolls on account of the greasy nature of its surface, which did not scale.

The finished bars were 1 inch round and 15 feet long, and were cut up into lengths of 9 inches. Each 9-inch length was turned up into a tensile test-piece with 2-inch parallel and $\frac{1}{2}$ inch in diameter.

The roughly turned test-bars were then submitted to heat treatment in an electrically heated tube furnace, the atmosphere of which could be made to consist of any desired gas. After treatment the bars were carefully turned up and tested.

It soon became evident that the effect of any heat treatment depended largely upon the presence or absence of reducing gases in the atmosphere of the furnace, as well as upon its temperature. Hence it became necessary to adopt a somewhat elaborate scheme of heat treatment.

Dislocation of the original scheme resulted from the fact that the authors were obliged to suit the convenience of the

* [See also Mr. Bengough's reply to discussion.—*Ed.*]

engineering department of the university by testing the treated bars in large batches. Thus they were working in the dark until they had obtained the results of the whole of the batch. Also it usually became necessary to begin heat treating the second batch before they had obtained the results of the first. This occasionally produced over-lapping and gaps in the scheme.

The scheme of heat treatment finally arrived at was as follows :—

Bars D and E were used mainly for thoroughly testing the effect of time and temperature of annealing in an atmosphere of air free from reducing gases. Thirteen test-pieces from each bar were used for this purpose. Four test-pieces of E and five test-pieces of D were used to confirm the results obtained on bar C as to the effect of reducing gases.

Bar C was used mainly for ascertaining the conditions under which reducing gases impaired the mechanical pro-perties of the bar. Eleven test-pieces were used for this purpose. Five other test-pieces were used to confirm and supplement the conclusions arrived at as to the effect of an ordinary oxidising atmosphere on these alloys, which effect had been more elaborately investigated on bars E and D.

Bar A contained only a very small quantity of arsenic, hence comparatively few tests were carried out on it. Four test-pieces were treated in a reducing atmosphere. Three test-pieces were treated in an oxidising atmosphere at temperatures indicated by the results obtained on other bars.

The mechanical properties of the bars are given in Tables II. to VII.

The authors wish to acknowledge here the obligation they are under to Mr. W. Donaldson of the Walker Engineering Laboratories of Liverpool University, who carried out for them the greater part of the mechanical tests described in this paper.

Table II.—*Tests on the Bars " as rolled."*

	Maximum Stress. Tons per Sq. In.	Yield Point.	Elongation per Cent. on 2 Inches.	Contraction per Cent.	Scleroscope No.
Bar A (0·04 per cent. arsenic)	15·5 15·6	6·0 6·5	58 58	80 78	11·5 to 15 * 11·5 to 15 *
Bar C (0·25 per cent. arsenic)	15·7 15·8	8·8 10·2	52 48	77 80	11·0 11·5
Bar D (0·75 per cent. arsenic)	15·7 15·6	6·3 6·1	59 55	80 79	11·0 11·0
Bar E (0·94 per cent. arsenic)	16·5 16·6	8·8 8·5	56 53	69 70	10·5 10·5
Bar B (1·91 per cent. arsenic)	17·0 16·8	6·7 6·4	62 62	81 80	10·5 10·5

* " Patchy."

Table III.—*Bar A (0·04 per Cent. Arsenic).*

Treatment.				Mechanical Tests.			
No. of Test-piece.	Time.	Temperature.	Atmosphere.	Maximum Stress. Tons per Sq. In.	Yield Point.	Elongation per Cent. on 2 Inches.	Contraction per Cent.
A8	...	As rolled	...	15·5	6·0	58·0	80·0
A3	...	,,	...	15·6	6·5	58·0	78·0
A4	...	,,	...	15·8	7·8	47·5	75·0
A7	3 hours	600° C.	Coal gas	15·6	6·2	44·0	12·0
A9	3 ,,	700° C.	,,	5·8	0·0	0·0	0·0
A1	3 ,,	800° C.	,,	2·2	0·0	0·0	0·0
A2	3½ ,,	800° C.	,,	2·5	0·0	0·0	0·0
A5	3 ,,	900° C.	Air	15·4	5·8	56·0	67·0
A6	3 ,,	900° C.	,,	14·5	4·5	56·5	70·0
A10	3 ,,	1000° C.	,,	12·3	2·3	18·0	23·0

TABLE IV.—*Bar C* (0·26 *per Cent. Arsenic*).

Treatment.				Mechanical Tests.			
No. of Test-piece.	Time.	Tempera-ture.	Atmos-phere.	Maximum Stress. Tons per Sq. In.	Yield Point.	Elonga-tion per Cent. on 2 Inches.	Contrac-tion per Cent.
C10	...	As rolled	...	17·6	9·7	47·0	68·0
C11	...	,,	...	15·7	8·8	52·0	77·0
C18	...	,,	...	15·8	10·2	48·0	80·0
C16	1 hour	900° C.	Air	16·0	6·7	52·0	33·0
C17 *	1 ,,	...	,,	14·1	4·8	39·0	75·0
C14	3 hours	...	,,	15·8	6·5	54·0	68·0
C15	3 ,,	...	,,	14·9	5·9	53·0	60·0
C19	3 ,,	1000° C.	,,	14·1	4·8	49·0	59·0
C9	1 hour	450° C.	Coal gas	15·6	5·1	55·0	77·0
C8	1 ,,	500° C.	,,	16·4	5·4	54·0	76·0
C7	1 ,,	600° C.	,,	16·2	3·5	54·0	71·0
C6	3 hours	600° C.	,,	16·1	5·8	46·0	63·0
C5	1 hour	700° C.	,,	9·6	5·0	9·5	Bar crumbled
C4	3 hours	700° C.	,,	4·6	0·0	1·5†	,,
C3	1 hour	800° C.	,,	5·2	0·0	0·0	,,
C2	3 hours	800° C.	,,	4·5	0·0	1·5†	,,
C1	4 ,,	800° C.	,,	4·6	3·8	0·0	0·0
C12	3 ,,	800° C.	Hydrogen	4·2	0·0	0·0	0·0
C13	3 ,,	800° C.	Carbon monoxide	4·3	0·0	0·0	0·0

* Heating furnace broke; heat treatment somewhat indefinite and probably more severe than that given.
† Broke outside gauge marks.

TABLE V.—*Bar D* (0·75 *per Cent. Arsenic*).

	Treatment.			Mechanical Tests.			
No. of Test-piece.	Time.	Tempera-ture.	Atmos-phere.	Maximum Stress. Tons per Sq. In.	Yield Point.	Elonga-tion per Cent. on 2 Inches.	Contrac-tion per Cent.
D19	...	As rolled	...	15·7	6·3	59·0	80·0
D20	...	,,	...	15·6	6·1	55·0	79·0
D1	½ hour	600° C.	Air	15·3	4·3	61·0	76·0
D5	½ ,,	600° C.	,,	15·1	4·0	58·0	82·0
D4	1 ,,	600° C.	,,	15·5	5·3	53·0	76·0
D2	1 ,,	600° C.	,,	15·8	4·8	52·5	81·0
D6	3 hours	600° C.	,,	14·8	4·4	40·0*	75·0
D3	3 ,,	600° C.	,,	14·6	5·3	51·0	80·5
D7	1 hour	700° C.	,,	15·3	...	57·0	...
D8	1 ,,	700° C.	,,	15·2	...	50·5	...
D10	3 hours	700° C.	,,	15·1	...	47·0†	...
D9	3 ,,	700° C.	,,	16·0	...	81·0	...
D14	½ hour	800° C.	,,	15·2	4·7	48·5	70·0
D12	1 ,,	800° C.	,,	15·7	5·9	51·5	70·0
D13	3 hours	800° C.	,,	15·1	5·8	49·0	68·0
D11	3 ,,	500° C.	Coal gas	15·7	6·7	56·0	81·0
D18	3 ,,	600° C.	,,	16·1	7·6	59·0	77·0
D15	4 ,,	700° C.	,,	7·3	3·6	5·0	0·0
D17	2 ,,	800° C.	,,	13·0	5·5	22·5	30·0
D16	4 ,,	800° C.	,,	14·9	5·1	57·5	70·0

* Bar broke on gauge points.
† Bar broke outside gauge points.

TABLE VI.—*Bar E (0·94 per Cent. Arsenic).*

Treatment.				Mechanical Tests.			
No. of Test-piece.	Time.	Tempera-ture.	Atmos-phere.	Maximum Stress. Tons per Sq. In.	Yield Point.	Elonga-tion per Cent. on 2 Inches.	Contrac-tion per Cent.
E	...	As rolled	...	16·5	8·8	56·0	69·0
E	...	,,	...	16·6	8·5	53·0	70·0
E0	1 hour	600° C.	Air	16·2	7·1	55·0	71·0
E4	1 ,,	600° C.	,,	16·0	6·8	50·0	70·0
E14	1 ,,	600° C.	,,	17·6	lost	54·0	69·0
E1	3 hours	600° C.	,,	16·1	8·7	49·0	68·0
E3	3 ,,	600° C.	,,	17·5	7·2	48 0	69·0
E5	½ hour	700° C.	,,	17·0	8·2	50·0	72·0
E2	1 ,,	700° C.	,,	15·9	6·5	48·0	72·0
E17	1 ,,	700° C.	,,	16·5	8·2	52·0	73·0
E19	3 hours	700° C.	,,	16·4	6·3	57·0	71·0
E16	3 ,,	700° C.	,,	16·1	6·4	56·0	72·0
E18	1 hour	800° C.	,,	16·3	6·7	55·0	72·0
E13	3 hours	800° C.	,,	16·9	7·4	49·0	67·0
E15	3 ,,	800° C.	,,	16·9	8·2	48·0	71·0
E11	4 ,,	700° C.	Coal gas	0·0	0·0	0·0	0·0
E8	1 hour	800° C.	,,	0·0	0·0	0·0	0·0
E7	2 hours	800° C.	,,	4·7	0·0	0·0	0·0
E9	4 ,,	800° C.	,,	3·9	0·0	0·0	0·0

TABLE VII.—*Bar B* (1·9 *per Cent. Arsenic*).

No. of Test-piece.	Time.	Temperature.	Atmosphere.	Maximum Stress. Tons per Sq. In.	Yield Point.	Elongation per Cent. on 2 Inches.	Contraction per Cent.
	Treatment.			Mechanical Tests.			
B1	...	As rolled	...	17·0	6·7	62·0	81·0
B2	...	,,	...	16·8	6·4	62·0	80·0
B13	1 hour	900° C.	Air	15·2	5·0	53·0	75·0
B14	3 hours	900° C.	,,	14·8	4·2	52·5	65·0
B10	3 ,,	1000° C.	,,	0·0 *	0·0	0·0	0·0
B12	4 ,,	1000° C.	,,	14·8	5·4	47·0	43·0
B11	3 ,,	1000° C.	,,	15·1	4·7	53·0	67·0
B8	1 hour	600° C.	Coal gas	16·6	6·6	58·0	80·0
B9	3 hours	600° C.	,,	17·0	7·6	58·0	71·0
B7	3 ,,	800° C.	,,	16·2	2·1	57·0	79·0
B3	3 ,,	800° C.	Carbon monoxide	16·1	5·8	56·0	79·0
B4	3 ,,	800° C.	,,	16·4	4·5	60·0	79·0
B5	3 ,,	800° C.	Hydrogen	15·9	6·2	59·0	80·0
B6	3 ,,	800° C.	,,	16·5	5·8	62·0	80·0
B15	3 ,,	900° C.	Coal gas	15·7	4·5	56·0	76·0

* Dropped in two on being withdrawn from furnace at a yellow heat.

General Notes on the Tables.

In these notes the term "burnt" is used to indicate that both the tensile strength and the elongation fall off simultaneously.

Bar A (0·04 *per Cent. Arsenic*).

The "as rolled" tests show this bar to be only moderately homogeneous. A possible cause of this is dealt with later. The patchiness is particularly noticeable in the scleroscope tests.

Oxidising Atmosphere.—Mechanical properties not seriously spoilt by being heated for three hours to 900° C.; nor, presumably, by less severe treatment. Seriously burnt by being heated for three hours to 1000°.

Reducing Atmosphere.—Mechanical properties ruined by treatment for three hours at 700° C.

Began to show signs of deterioration after being heated for three hours to 600°.

Bar C (0·25 *per Cent. Arsenic*).

Bar very unhomogeneous. Yield-point unusually high.

Oxidising Atmosphere.—Heat treatment at 900° C. considerably lowered the yield-point, but otherwise did not impair or improve appreciably the mechanical properties.

Reducing Atmosphere.—Mechanical properties ruined by one hour at 700° C., or by treatment for a longer time at that or higher temperatures.

Ductility slightly impaired by heating to 600° C. for three hours.

After one hour at 600° the mechanical properties somewhat resembled those shown by the bar "as rolled," but the ductility not appreciably raised.

The yield-point was notably lowered even by heat treatment for one hour at 450° C.

The structure of this bar, both "as rolled" and after treatment in coal gas, is shown in Plate I., Figs. 1 to 3 ; the dark lines and patches are cracks and holes.

Bar D (0·75 *per Cent. of Arsenic*).

Bar fairly homogeneous.

Oxidising Atmosphere.—Yield-point lowered by treatment for half-an-hour at 600° C. Other mechanical properties appear to be independent of heat treatment at temperatures below 800° C., and are only slightly impaired at that temperature.

Reducing Atmosphere.—Mechanical properties unaffected at 600° C., but ruined by treatment at 700° C.

At 800° C. two bars appeared to resist the action of reducing gases, in part at any rate. The authors, in explanation of this result, can only suggest that a skin of some kind formed on the surface of the alloy and prevented the penetration of the gases.

Bar E (0·94 per Cent. of Arsenic).

Bar very homogeneous.

Oxidising Atmosphere.—Mechanical properties practically unaffected by any treatment less severe than three hours' heating at 800° C.

Reducing Atmosphere.—Bar ruined by treatment for four hours at 700° C.

Bar B (1·9 per Cent. Arsenic).

Bar very homogeneous. Gave the best mechanical tests of the whole series of alloys. The structure of this bar "as rolled," and after treatment in reducing gas, is illustrated in Plate I., Figs. 5 and 6.

Oxidising Atmosphere.—Except that the yield-point and elongation are somewhat lowered, the bar was not much affected by treatment in three hours at 900° C.

The difference between the strength of bars *at* high temperatures and after only being *heated* to high temperatures and subsequently tested *cold*, is clearly brought out by the results on bars B10 and B12.

Fig. 11 (Plate II.) shows the structure of bar B10, which was withdrawn from the furnace at a temperature of 1000° C.; it immediately dropped in two. The arsenic has segregated; the light portion being arsenic-rich. The dark areas in the light bands are eutectic areas, which form an almost continuous network of weak, brittle material round the large, black, copper-rich portions.

Reducing Atmosphere.—This bar completely resisted the action of reducing gases. The tests on bar 13 and bar 15, which had both been heated for three hours at 900°, the former in an oxidising and the latter in a reducing atmosphere, are practically identical.

Scleroscope Tests on the Bars " as rolled."

Experiments, described elsewhere in this paper, have shown that arsenic raises the scleroscope number slightly when added in small quantities. Practically identical numbers were, however, obtained for the rolled bars. In general " work " also raises the number, and in this case this effect masks the effect of the arsenic.

Summing up generally the results of the mechanical tests, it may be said that—

1. Arsenic in small quantities tends to increase the maximum stress without affecting appreciably the ductility of these alloys.

2. It increases their resistance to reducing gases at high temperatures.

3. Alloys with low percentages of arsenic tend to be unhomogeneous, but with increase in the arsenic this ceases to be apparent. Slight heterogeneity is probably an inherent defect of low arsenic alloys.

4. In ordinary oxidising atmospheres no heat treatment (for three

hours or less), short of an approximation to fusion, seriously affects the properties of these alloys. The only result of annealing is to render the bars slightly more homogeneous, and to lower the yield-point somewhat. This statement, however, does not apply to annealing temperatures in the neighbourhood of 1000° C.

5. Alloys containing less than 1 per cent. of arsenic are ruined by the action of reducing gases for three hours at 700° C. or above it; in some cases the action is apparent at 600° C. It is probable that a shorter heating period would also be harmful.

6. The yield-points of these alloys are somewhat variable and unsatisfactory.

It is interesting to note that the 1·9 per cent. alloy has very nearly the same properties as the 2·1 per cent. copper aluminium rolled bar of similar dimensions described by Carpenter and Edwards on p. 76 of their report to the Institution of Mechanical Engineers.[13] This means that the addition of small quantities of As and Al have practically the same effect on the mechanical properties of copper.

It may be mentioned that the results obtained by the authors are markedly better than those obtained by W. Stahl and by E. A. Lewis, already quoted. Lewis's bars, however, were made from small 8-lb. crucible charges, and were rolled down to ⅛ inch thickness, and so are not strictly comparable with the authors' bars.

Section B.—Discussion of the Causes of the Failure of the Alloys.

It was found early in the work that coal gas had a ruinous effect on the bars. The gas used was ordinary Liverpool town gas, which had the following approximate composition:—

	Per Cent.
Marsh gas	35·0
Other hydrocarbons	0·5
Hydrogen	50·0
Carbon monoxide	12·5
Carbon dioxide	1·0
Nitrogen	1·0

It was thought desirable to find out which of these gases was the actual spoiling agent.

Accordingly bars B5, B6, and C12 were heated in an atmosphere of pure hydrogen, and bars B3, B4, and C13 were heated in an atmosphere of carbon monoxide. The following was the average composition of the latter gas:—

	Per Cent.
Carbon monoxide	86·0
Carbon dioxide	2·1
Oxygen	3·3
Nitrogen	8·6

It was made by passing oxygen from a cylinder over a long column of charcoal, heated to a bright red heat in a silica tube placed inside the fire-clay tube of an electrical resistance furnace.

It will be seen from the tables of tests that the effect of hydrogen and carbon monoxide is practically identical with that of coal gas. The conclusion to be drawn seems clearly to be that the one property which all these gases have in common, namely, their reducing action, is the cause of the ruin of the bars heated in them.

The establishment of this fact considerably shortened and simplified the investigation of the causes of failure of these bars.

It rendered it unnecessary to take into consideration the formation of hydrides such as copper is known to form in certain wet reactions. It also rendered it unlikely that the copper was broken up and disintegrated by the repeated temporary formation and subsequent decomposition of certain unstable compounds, such as occur when copper is treated for long periods in ammonia gas. In fact, it narrowed the investigation down at once to the relations of copper, oxygen, and arsenic.

The authors have not had sufficient time at their disposal to make a complete investigation of this triple system. It seems possible that a thorough understanding of the causes of failure of these alloys cannot be obtained without it. A few preliminary experiments, however, have been made, and these appear to throw some light on the matter.

It was noticed that several of the bars which failed in the reducing gases showed cracks on their surfaces plainly visible to the naked eye; in other cases the cracks were only visible with the aid of the lower powers of the microscope (Plate I., Figs. 2 and 3). In one way or the other cracks could be detected in all cases in which failure occurred in reducing gases. It seemed probable, therefore, that the cause of failure was some intense reaction taking place in the interior of the alloy, and was not simply the rearrangement of the structural constituents or crystalline habit, such as occurs, for example, in bars burnt by heating to a high temperature in an oxidising

atmosphere. In the latter case it seemed probable that the plasticity of the copper at the high temperature at which the ruin took place would have enabled it to "give" to the small extent required to prevent it from cracking.

The question, then, that immediately suggested itself was, does some violent reaction occur between such reducing gases as hydrogen and carbon monoxide, and such oxides as cuprous and arsenious oxides?

The first step towards investigating this point was to heat pure electrolytic cathode sheet copper, which contained no oxide of any kind, in the reducing gases.

The experiment was carried out under exactly the same conditions of time and temperature as produced ruin in the bars, namely, three hours at $800°$ C. No signs of cracks could be discovered, even under the highest powers of the microscope.

The next step was to melt down pure electrolytic copper in the wind furnace, under such conditions that a minimum or no oxidation could take place, and then to heat the ingot so obtained in reducing gases as before. This step was thought to be necessary in case the casting process had any influence on the results. Again no cracks could be found.

Electrolytic copper was next melted down with free access of air, and the resulting ingot treated like the others. Again no cracks could be detected. Evidently, then, the intense reaction sought for was not directly associated with the presence of cuprous oxide.

In the next experiment arsenious oxide, carefully wrapped up in copper foil, was added to molten electrolytic copper in the crucible, in sufficient quantity to produce an alloy of about 2 per cent. of arsenic. Analysis showed 1·8 per cent. of arsenic. Plate II., Figs. 8 and 9, show the appearance of this specimen under the microscope. The fern-like crystals and the smaller specks are crystals of arsenious oxide, which looked grey under the microscope. No true eutectic of copper and arsenious oxide was formed, and the phenomenon appears to be similar to that investigated by Mons. Giraud ([12]) for the system copper, copper-oxide.

A specimen of this alloy was heated as before in coal gas. The alloy was not merely cracked, it was literally shattered

D

to pieces.   The structure of a small portion of the shattered alloy, showing fine cracks and holes, is shown in Plate II., Fig. 7.   Oxide is no longer visible.   Analysis showed, however, that there was no loss of arsenic, evidently the oxide has been reduced, and the arsenic has passed into solid solution.

In order to give a striking comparison, an alloy was next made under exactly the same conditions, using metallic arsenic instead of the oxide.   The structure of this alloy as cast is shown in Plate II., Fig. 10, for comparison with Figs. 8 and 9. On heating in coal gas as before, this alloy showed but a few small cracks, and was by no means shattered, as was the case with the last alloy.   The explanation of this was thought to be that the arsenic reduced any copper oxide present in the molten copper, forming arsenious oxide in small quantity; this was subsequently reduced with the production of cracks.

To test this the following experiment was made : Arsenic was added to copper melted under conditions under which no cuprous oxide could be formed, and the resulting alloy was allowed to cool in the crucible.   On being subsequently heated in reducing gases no cracks could be found.

These experiments, taken in conjunction with those carried out on the bars, seem to point to the following conclusions :—

1. At temperatures above 650° C. hydrogen and carbon monoxide can penetrate and travel freely about in metallic copper and its alloys with arsenic containing less than 1·5 per cent. of arsenic.   In some cases the penetration is not very rapid, and bar A9 affords an interesting example of this. The tensile fracture of the bar shows clearly by the alteration in colour the distance to which the gas has penetrated.   A circular crack, a little nearer the shoulder, extends only as far as the gas has penetrated.   The interior core has some ductility, and the bar in consequence can be bent backwards and forwards at this point.   (Specimen shown.)

2. The gases are probably in solution in the alloy.

3. The gases have no serious effect on the alloy if the following conditions are fulfilled :—

    (*a*) The alloy contains no oxide.

    (*b*) The alloy contains oxide, but is not heated in contact with reducing gases.

4. The gases ruin the alloys after being heated to about 650° in their presence, and if the alloy also contains oxide in the form, probably, of arsenious oxide. Oxides of certain metals other than arsenic are possibly equally harmful, but no experimental data are at present available on this point. Cuprous oxide is harmless, as far as the effect now being dealt with is concerned.

5. The actual cause of the ruin of the alloy seems to be a sudden evolution, and subsequent expansion, of steam or carbon dioxide, formed as a result of the reaction between hydrogen or carbon monoxide and arsenious oxide in the interior of the mass of metal; the gases resulting from the reaction are probably insoluble, or only very slightly soluble, in solid copper; hence their destructive reaction.

6. Metallic arsenic can probably reduce cuprous oxide contained in molten copper. (It by no means necessarily follows from this that cuprous oxide must be more easily reducible than arsenious oxide at temperatures lower by several hundred degrees. Experiments are now being made to determine the conditions under which these oxides are actually reduced, both separately and in presence of one another.)

In view of the above the following considerations suggest themselves: When small quantities of arsenic are added to copper the reaction between it and cuprous oxide may very probably not be complete; hence the alloy may contain metallic arsenic in solution, and cuprous and arsenious oxides irregularly scattered about in it. After casting, the arsenic in solution will give rise to " cores," and the structure of the cold alloys will be by no means homogeneous. Moreover, the reaction may not proceed to the same extent at all points in the crucible, owing to local differences of temperature, pressure, and composition. Hence the resulting ingot will not be very homogeneous. In the presence of larger amounts of arsenic, however, the reaction is more likely to proceed to completion, thus all the cuprous oxide will be reduced, and the result will be more homogeneous ingots and finished bars. Hence bars high in arsenic should be more homogeneous than those lower in arsenic. This is in accordance with what the authors have found in practice.

Another point of interest is the possibility of endowing these alloys with the property of resisting the action of reducing gases. If the above reasoning be correct, all that is necessary for this is to remove completely the arsenious oxide. This could probably be effected by a period of tranquil fusion in the furnace, enabling the oxide to float to the top. Great care would have to be taken during this period to prevent the oxidation of the alloy, by keeping the crucible suitably covered and low down in the furnace. The loss of arsenic would probably be proportional to the period of tranquil fusion adopted, and would have to be allowed for. During pouring, the oxidisation of the copper, which is present in large excess, would take place to some extent; probably this would not affect the result, since the rapid solidification of the alloy in an iron mould would prevent further reaction between the arsenic and the copper oxide.

Experiments to settle the practicability of such procedure could not be successfully carried out in a laboratory on a small scale, and have not been attempted. Full-sized charges should be used under normal working conditions. The results obtained would probably be very interesting.

The authors wish to point out here that the remarks set forth above are merely tentative, and are based on only a few experimental results. They are intended mainly to provoke a discussion which, it is hoped, may prove fruitful in clearing the way for future work.

SECTION C.—METHODS OF ANALYSIS.

Analysis of the Alloys.—For all alloys described in Part II. of the paper, and containing from 2 to 44 per cent. of arsenic, the distillation method was used, and was found to be satisfactory. It was carried out as follows. The distillation mixture was :—

Ferric chloride	215 grammes
Calcium chloride	280 ,,
Hydrochloric acid	...
Total	1 litre

From 0·5 to 1 gramme of the alloy was placed in a round-bottomed flask with 70 cubic centimetres of the above mixture, and evaporated to syrupy consistency, the distillate of arsenious chloride being absorbed by about 50 cubic centimetres of water in a U tube. The contents of the tube were washed into a beaker, and then nearly neutralised with ammonia; a few grammes of sodium bicarbonate were added, and the whole tritrated with decinormal iodine solution.

Alloys containing up to 25 per cent. of arsenic were sampled, either by drilling a central hole through the ingot, or by turning a deep groove round it in the lathe, surface turnings being rejected. Alloys containing more than 25 per cent. of arsenic were too hard to be turned, so a small piece was sawn out of the ingot and finely powdered in an agate mortar. Rich arsenic alloys do not dissolve readily in the distillation mixture, unless in a finely divided state.

For alloys with less than 2 per cent. arsenic centinormal iodine solution had to be used, and in this case the end point of the tritration became rather indefinite. This has since been shown to be due to small amounts of pyrrole ([8]) in the ammonia. At the time the authors were not acquainted with the method of purifying the ammonia with permanganate, and therefore had to employ other methods for estimating small amounts of arsenic.

The following method was principally used :—

The sample was distilled with the mixture above described, but dilute nitric acid was placed in the U tube, into which the arsenious chloride was passed. At the close of the distillation this liquid was boiled with the addition of a little more nitric acid, and then neutralised with ammonia. The arsenic was then estimated as magnesium pyrarsenate in the usual manner.

PART II.—THE CONSTITUTION OF COPPER-ARSENIC ALLOYS.

Section D.

General Scheme of the Work.—As explained in the introduction, the work described under this heading was under-

taken with the object of checking the curves and conclusions
arrived at independently by Hiorns and Friedrich, which did
not agree well with one another. Hiorns' diagram (Fig. 2)
has been carefully enlarged from his tables of data and the
original figures, so as to be readily comparable with the
authors' own diagram (Fig. 3). The latter agrees fairly
well with Friedrich's, and the differences between them will be
discussed later. Both differ from Hiorns' in some important
points, and these will now be described.

The chief points of difference are :—

(*a*) The change in direction of the liquidus given by
Hiorns at about 15 per cent. arsenic. This might have
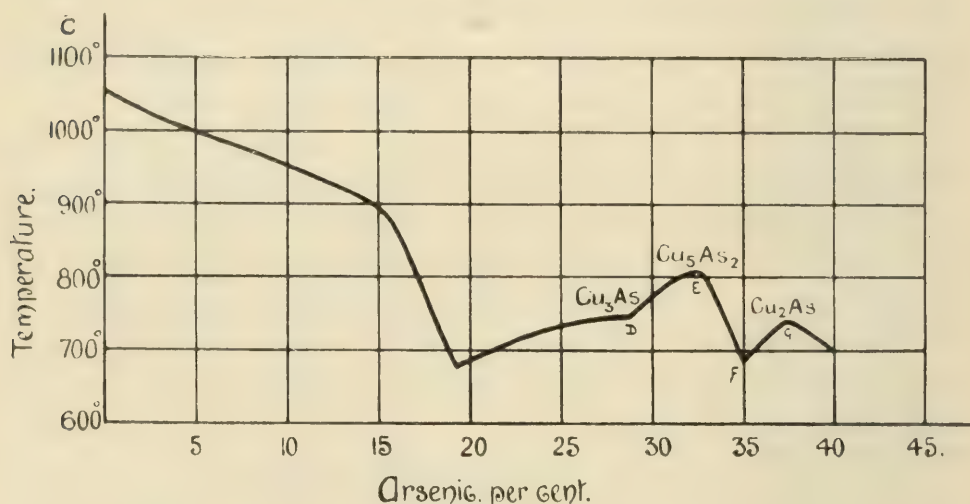
FIG. 2.—Copper-Arsenic Alloys (Hiorns).

been overlooked by Friedrich, as he only examined a small
number of alloys below the eutectic composition 21·5 per
cent. arsenic. If verified, this inflection of the curve might
mean that different solids were in equilibrium with the liquid
on each side of the concentration at which it occurs, and
this might have an important bearing on the composition of
the β phase, which produces brittleness in these alloys. The
authors' results agree with Friedrich's.

(*b*) The summits at D, E, and G on Hiorns' curve do not
occur in Friedrich's, who gives instead of them a single
summit at 29 per cent. of arsenic and 830° C. Hiorns'
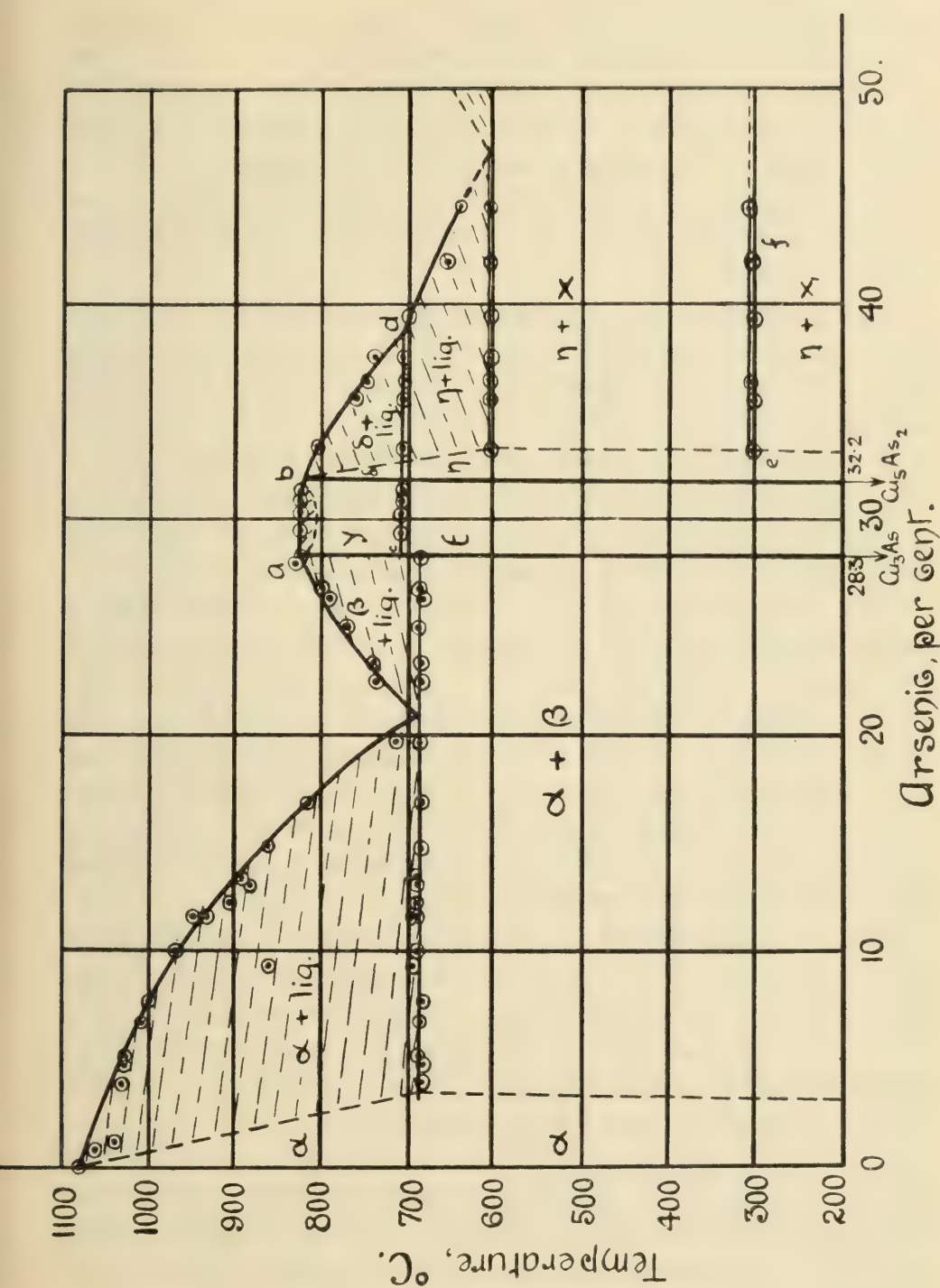
FIG. 3.

maximum at E, which most nearly corresponds to this temperature, but is still 20° below it, occurs at 32·19 per cent. The authors' results agree with Friedrich's.

(*c*) The minimum at F in Hiorns' curve, occurring at about 25 per cent. of arsenic, does not correspond to anything either on the authors' or Friedrich's diagram.

The authors have endeavoured to improve to some extent upon the methods used by the former workers, in the following ways :—

1. They have used larger quantities of alloys for the determination of all critical points, namely, a minimum quantity of 250 grammes, as against 30 grammes used by Friedrich and 32 grammes by Hiorns.

2. They have examined a larger number of alloys.

3. They have used a more accurate pyrometric method.

4. They have used a mode of investigation not used by either of the previous workers, namely, a series of scleroscope tests.

The Determination of the Critical Points.—Hiorns used a direct reading method, the details of which are not given in his paper. Friedrich used a direct-reading Siemens and Halske millivoltmeter, graduated from 0° to 1600° C. The smallest division on the scale represented 10° C. The use of an instrument with such a close scale as this for the determination of the critical points of an alloy, and also for thermal analysis, cannot be considered as quite satisfactory, as has been already pointed out by Rosenhain ([9]).

The authors have used a thermocouple of platinum platinum-iridium for nearly all the measurements. Its indications were observed by one of two instruments :—

1. A direct-reading " thread recorder " made by the Cambridge Scientific Instrument Company.

2. A Carpenter-Stansfield potentiometer.

The latter instrument has been described in detail by Messrs. Carpenter and Keeling ([10]), and is now too well known and appreciated to require any description here. The " thread recorder " is less well known, and a short description of it, and its application to the present work, is given in the note on " The Uses and Limitations of the Thread Recording Pyrometer," following this paper.

The temperatures of all important critical points were measured by the potentiometer, *e.g.* the exact solidification temperatures of all the eutectics; the points on the summit of the curve A, B; and points in the neighbourhood of 15 per cent. arsenic, where Hiorns' curve shows an inflection.

The temperature of intermediate points of less importance were determined by the "thread recorder." This is an exceedingly convenient instrument in use, and does not require the same amount of close attention as the potentiometer. It is, of course, much less sensitive than that instrument, but is more sensitive than the instrument used by Friedrich, and has the additional advantage of being independent of personal equation.

Preparation of the Alloys.—The alloys used in this part of the investigation were prepared in the laboratory from pure electrolytic copper, obtained from Messrs. Bolton of Widnes, and Kahlbaum's "refined" arsenic. Analysis of the latter material showed :—

		Per Cent.
Iron	. . . .	0·06
Lead	. . . .	trace
Antimony	. . . .	trace
Sulphur	. . . .	0·16
Tin and insol. in HNO_3	. . . . . .	0·09
Arsenic (by difference)	. . . . . .	99·69

The alloys were prepared by melting down the required amount of copper in a carbon crucible in a wind furnace, and adding the second metal—either as metallic-arsenic, or as a rich copper-arsenic alloy, containing about 44 per cent. of arsenic. The resulting alloy was stirred with an electric arc carbon, and, when thoroughly mixed, was transferred to a previously heated fire-clay injector furnace. If there were any danger of the alloy solidifying too soon, the heating of the furnace was continued for a minute or two after the crucible had been placed in it; otherwise the gas was turned out, the entrance for it closed by a fire-brick, and the thermojunction at once introduced, and the cooling curve taken. The object of taking the curve straight away was to avoid loss of arsenic by remelting, since these losses were frequently large in amount and irregular in distribution.

Protection of the Couple.—With some of the alloys high in arsenic considerable trouble was encountered, from the fact that arsenic vapours readily attack platinum and its alloys, rendering them brittle and useless for pyrometric work. A number of different protecting tubes were tried, both plain and glazed with various substances. Finally the authors adopted thin silica tubes, 6 inches long, with one lead in a narrow inner insulating tube, and the outer tube glazed with salt. This arrangement answered well. Unfortunately the research had already become expensive in platinum before it was discovered, and in a few very bad cases it had been necessary to cut off from 3 to 6 inches of wire, and repeat the experiment. Platinum couples that had been in use for some time seemed more liable to attack than newer couples.

Rate of Cooling.—The rate at which the alloys were cooled during the pyrometric work was slowed down to a certain extent by pre-heating the gas furnace to a high temperature before introducing the crucible of molten alloy, and also by closing the top and gas entrance by means of heated fire-bricks and asbestos packing. This arrangement prevented stirring, but the records obtained did not in general show signs of surfusion. An inspection of the diagram, Fig. 3, will show, however, that surfusion probably did take place in a few cases, especially at the copper-rich end of the series. Accordingly the liquidus has been drawn preferentially through the highest points obtained. The average rate of cooling was about 20° per minute between 900° and 500°. Friedrich, in his second paper, gives his rate of cooling as 75° per minute at 1000°, and states that " a lower rate was forbidden for arsenic-rich mixtures, because they are very unstable, and in a short time lose much arsenic by volatilisation." This is no doubt true for the small specimens, usually only 30 grammes in weight, used by Friedrich. In larger specimens (250 grammes) the authors consider that the loss is largely confined to the outside layers, and will not very greatly affect the determination of the critical points by the thermojunction, if it be placed centrally, at any rate for the speed of cooling employed by the present authors.

The two instruments usually employed for the pyrometric

work have been referred to, and one of them is described, elsewhere. The potentiometer only became available for use towards the end of the work, or it would have been much more largely employed.

The zero of the thread recorder was at 400° C. Consequently for the temperature range 400° C. to 0° C. the authors decided to fall back on a nitrogen-filled mercury thermometer. This was found to be satisfactory. The rate of cooling averaged 15° per minute. All the points on the line e, f of the diagram were determined in this way. About 35 grammes of the coarsely crushed alloy were used. In all other pyrometric work not less than 250 grammes were used.

Analyses of the Alloys.—The methods used in the analysis of the alloy have been dealt with elsewhere. In all cases the analyses were carried out after the cooling curve had been obtained, and before the alloy had been again heated for any purpose. Nearly all the alloys lost arsenic very readily when heated, even to quite low temperatures, and far below their melting-point. Alloys occurring in the range of concentration between the points a and b on the liquidus curve appeared to lose arsenic rather less readily than those in the neighbouring ranges. In general the authors have found, with Friedrich, that the loss of arsenic decreases in passing from the outside of a mass of the alloy to the inside, and this complicates the analysis. The authors agree with Friedrich in putting the limit of arsenic contents with which these alloys can be satisfactorily prepared and examined at about 44 per cent. of arsenic. The richest alloy for which we give full data contains 44·4 per cent.

A list of the alloys, with their critical points, is given in Table VIII. In the note on " The Uses and Limitations of the Thread Recording Pyrometer," following this paper, comparative results with the recorder and potentiometer are given.

Consideration of the Diagram.—From the pyrometric data and the micrographic work carried out on the same set of alloys, the diagram given in Fig. 3 has been constructed. This will now be described and compared with that of Friedrich, and, as far as the liquidus is concerned, with that of Hiorns.

TABLE VIII.—*Table of Alloys and Critical Points.*

Alloy.	Per Cent. Arsenic.	Critical Points.				
		A.	B.	C.	D.	E.
...	0·0	1084	...	...	...	...
E	0·9	1065	...	...	...	...
F	1·3	1050	...	...	...	..
F″	2·5	...	...	...	...	...
Q	4·0	1035	685	...	...	...
J	4·8	1030	685	...	...	...
F′	5·1	1030	685	...	...	...
O	6·8	1012	688	...	...	...
O″	7·8	1000	685	...	...	...
G	9·4	863	697	...	...	...
G′	10·0	970	690	...	...	...
G″	11·7	930	690	...	...	...
K″	11·7	932	690	...	...	...
K	12·2	905	687	...	...	...
K′	13·1	885	688	...	...	...
K″	13·3	888	690	...	...	...
L	14·9	860	694	...	...	...
M	19·6	715	685	...	...	...
H	16·9	820	690	...	...	...
P	22·5	740	685	...	...	...
M′	23·3	742	685	...	...	...
R	25·0	770	690	...	...	...
V	26·3	790	687	...	...	...
N	26·9	800	690	...	...	...
I	28·0	832	?	...	...	...
V′	28·3	830	685	...	...	...
I′	29·6	830	...	710	...	...
S	30·3	830	...	710	...	...
S′	30·8	830	...	710	...	...
X	31·2	830	...	708	...	...
T′	33·4	807	...	708	600	303
T	35·7	760	...	710	600	303
W	36·3	755	...	707	600	306
U	37·5	740	...	710	600	?
Y	42·0	650	...	...	601	301
Y′	39·3	700	...	...	600	305
Z′	44·4	635	...	...	600	305

The liquidus between 0° and 44 per cent. of arsenic consists of five branches, along which the five phases α, β, γ, δ, η begin to separate from liquid alloy. The phase α can hold about 3 per cent. of arsenic in solid solution at the ordinary temperature, and after the rates of cooling used in this research. Fig. 12 (Plate II.) shows an alloy with 2·5 per cent. of arsenic, and Fig. 13 (Plate III.) one with 4 per cent. of arsenic. The former shows only one constituent and " cores." The dark parts are the

copper-rich parts. Fig. 13 shows two constituents, the second constituent crystallising out of the arsenic-rich or lighter parts. In view of the work of Rosenhain and Tucker[11], it was thought desirable to anneal some specimens for a long time at a low temperature, to test the influence of rate of cooling on the amount of arsenic held in solid solution. Fig. 15 (Plate III.) shows a specimen containing only 1·3 per cent. arsenic, which had been annealed for thirty hours at 425° C. The second constituent has crystallised out, and it appears, especially in the centre of the bottom part of the figure, in segregated masses, surrounded by a network of small cracks. Being very brittle, it readily cracks, and drops out during the polishing process. It is evident that crystallisation from solid solution in these alloys is a slow process, requiring time for its completion, and that alloys, as ordinarily cast, are supersaturated with respect to β. This is the reverse of the result obtained by Rosenhain and Tucker[11] in the case of the lead-tin alloys, and on that account is especially interesting. It has been confirmed in four alloys of different compositions.

A first eutectic point occurs at 21 per cent. of arsenic, and its solidification temperature is 685° C. Figs. 16 and 17 (Plate III.) show the eutectic with excess of α and excess of β respectively. The constituents of the eutectic are the α phase, which is copper containing about 3 per cent. of arsenic in solution, and the β phase, which is considered to be the pure compound Cu_3As, containing 28·3 per cent. of arsenic. The evidence for the existence of this compound is as follows :—

1. Alloys of this composition solidify sharply at one temperature, namely, 830° C.

2. The microstructure shows only one constituent.

3. The eutectic appears on adding to the alloys the merest trace of copper; if, on the other hand, arsenic be added, a new change appears in the resulting alloy at 710° C.

This evidence the authors consider sufficient to establish the existence of the compound. Its existence has already been announced by Hiorns and Friedrich. The former made a shrewd guess at its existence from the fact that an alloy of this composition was homogeneous. The "kink" in the liquidus with which he further supported his claim has been

shown by Friedrich and the authors to have no existence, and his freezing-point for this alloy was some 80° too low. Friedrich's claim, on the other hand, was based on evidence similar to our own.

On passing beyond 28·3 per cent. of arsenic the author's diagram differs from those of the earlier workers. That of Hiorns will not be further alluded to, since he was only dealing with the liquidus, and made no attempt to take into account the various changes that occur at lower temperatures. The authors propose, therefore, to describe their own diagram first, and then to indicate the points in which it differs from Friedrich's.

The branch of the liquidus along which the phase γ begins to separate from the liquid alloy is almost horizontal for a range of about 4 per cent., *i.e.* until a concentration of 32·2 per cent. of arsenic is reached. Six alloys have been examined in this narrow range, and one of them containing 28·3 per cent., as is not very clearly shown on the diagram. The inclination of the curve to the horizontal cannot be more than 5° C. through this range. A concentration of 32·2 per cent. corresponds to that required by the formula Cu_5As_2, and the question arises whether a second chemical compound of this composition exists at the point given by the further end of the horizontal branch of the curve. The authors think that it does, though the evidence for its existence is not quite as conclusive as that for the other compound; it is as follows:—

1. An alloy within 1 per cent. of the required composition solidifies practically at a definite temperature which is nearly 830° C.

2. It is homogeneous under the microscope (Plate III., Fig. 18). (Owing to too slow cooling decomposition is just beginning at the dark patch on the right-hand side of the figure.)

It undergoes a polymorphic change at a temperature in the neighbourhood of 710°, and with the aid of the recording pyrometer the authors have endeavoured to apply Tammann's method of thermal analysis to the energy change occurring at this temperature, in order to ascertain whether it reaches the maximum value at the 32·2 per cent. alloy. The results obtained, however, do not appear to be sufficiently definite

or trustworthy for publication. Friedrich has examined four alloys in this neighbourhood by the method, using his milli-voltmeter, and states that the greatest energy change, *i.e.* the greatest time of halt on cooling, does occur at this percentage. This is to be expected if the compound Cu_5As_2 separates at $830°$ C. and undergoes a polymorphic change at $710°$. In view of recent discussions, however, it is difficult to decide precisely what value is to be attached to this observation.

On the whole, however, the authors are inclined to adopt the view that two compounds, Cu_3As and Cu_5As_2, separate at points a and b on the liquidus curve. Between these two points a series of solid solutions of the two compounds occur. It so happens that the two compounds have nearly the same freezing-points, and the curve between them is very nearly a straight line. The solidus lies very close to the liquidus, as indicated on the diagram, but it cannot be traced with any great degree of accuracy, and consequently it is dotted in. Alloys at all points in the field marked γ are found to be solid and homogeneous. What, then, is the interpretation of the inversion at $710°$, which can be traced not only across this field, but also across the neighbouring solid and liquid fields marked δ and $\delta +$ liq. ?

If the existence of the two compounds be admitted, the δ phase is obviously the compound Cu_5As_2, which can hold up to about 1 per cent. of an unknown phase x in solid solution at $600°$ C. It follows, therefore, that the inversion at $710°$ follows the compound Cu_5As_2 into its solutions in both direc-tions. Hence the compound must preserve its identity, in part at any rate, even in solid solution. This is true even when it is forced by the presence of excess of another con-stituent to assume a crystalline habit foreign to its natural one, as will be the case with the alloy I′, for instance, which contains $29·6$ per cent. of arsenic.

The inversion at $305°$ C. appears to be a polymorphic change in the unknown phase x, since, roughly speaking, it appears to increase in importance with increase in arsenic. The experimental results, however, are not very clear on this point. The present authors are not able to trace this change to quite such a low concentration in arsenic as does Friedrich.

Microscopic Results.—The structure of the alloys from 0 to 28·3 per cent. is sufficiently represented by Figs. 13 to 17 (Plate III.), and have been dealt with already.

Beyond 28 per cent. of arsenic it became necessary to anneal and quench large numbers of specimens, in order to examine the changes which take place at the critical temperatures. In all chilling experiments an electrical resistance furnace was brought to the required temperature, the specimen was introduced, kept there from five to fifteen minutes, and then quenched in water. It was very necessary to reduce as far as possible the loss of arsenic by volatilisation. In order to examine the change that takes place, for instance, at 710° along the line *cd*, alloys must be brought to equilibrium at temperatures both above and below that temperature, and then be quenched and examined. It is quite certain, however, that a period of five, or even fifteen minutes, is insufficient to produce equilibrium at 730° C., but the authors hoped that by the procedure adopted it might be possible to obtain an idea of the change taking place. If a much longer annealing period were adopted the microscopic results became useless, owing to the great loss of arsenic.

In addition to the impossibility of obtaining true equilibrium, another difficulty was met with. In the range between 28 and 32 per cent. of arsenic the alloys were exceedingly brittle. They could not be gripped in the vice nor sawn, and the slightest mechanical stress produced confused structure showing twinning, altered material, and cracks. The interpretation of the structures was in consequence difficult.

Fig. 19 (Plate IV.) is a photo-micrograph of an alloy containing 30·8 per cent. of arsenic, quenched after annealing for five minutes at 730° C. It shows γ partly changed to ϵ. With this should be compared Fig. 18 (Plate III.), which shows nearly homogeneous γ, with very little of the broken-down structure.

Fig. 20 (Plate IV.) shows alloy T′ containing about 33 per cent. of arsenic, quenched after being annealed for five minutes at 730°. The field consists mainly of δ partly broken down to η.

Fig. 21 (Plate IV.) shows an alloy containing 37·0 per cent. of

PLATE I

FIG. 1.—Bar C. α. As rolled. Magnified
150 diameters.
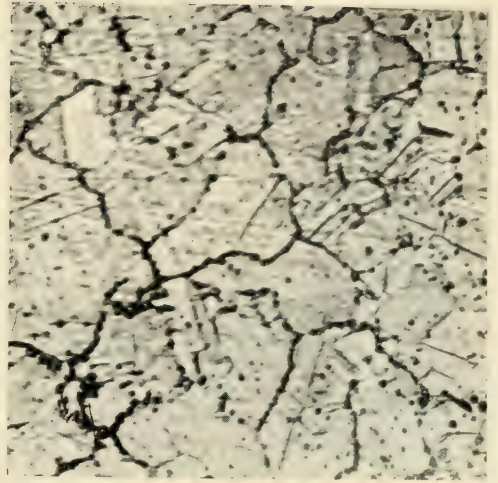
FIG. 2.—Bar C. α+cracks. Four hours in coal
gas. Magnified 150 diameters.
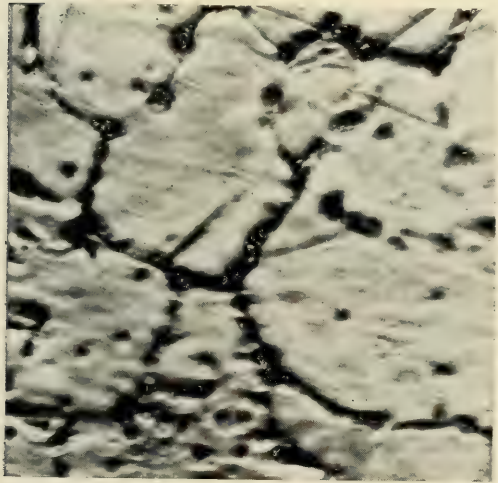
FIG. 3.—Bar C. α+cracks. Four hours in coal
gas. Magnified 550 diameters.
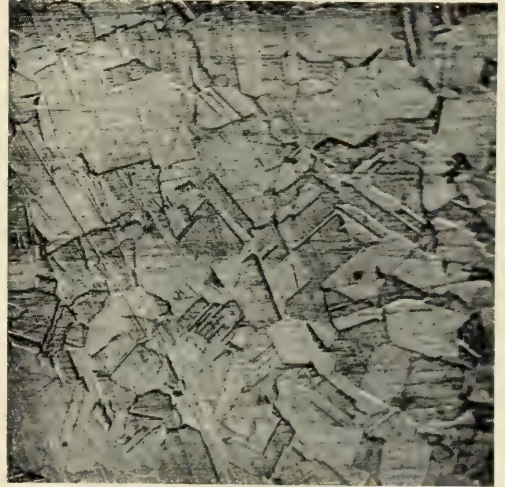
FIG. 4.—Bar B. As rolled. α.
Magnified 150 diameters.
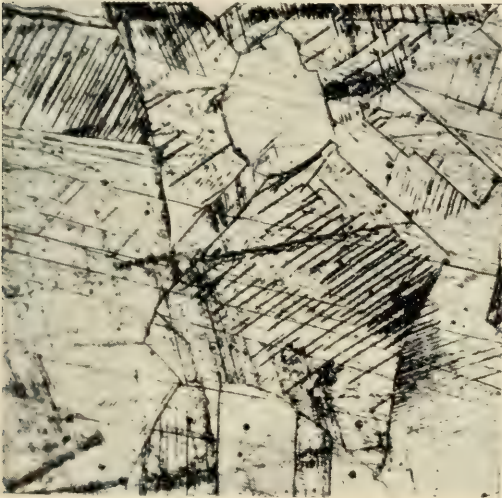
FIG. 5.—Bar B. α+Cu₃As. Three hours in carbonic
oxide. Magnified 150 diameters.

FIG. 6.—Bar B. Three hours in carbonic oxide.
Magnified 500 diameters.

All specimens etched with dilute ammonia.

PLATE II
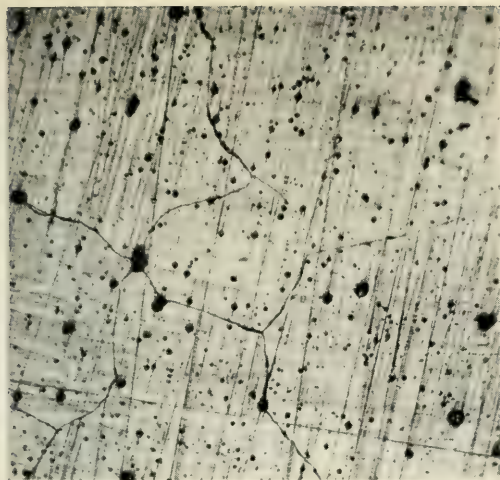
FIG. 7.—Arsenic, 1·8 per cent. α + crack and holes. Reduced in coal gas. Magnified 50 diameters.

FIG. 8.—Arsenic, 1·8 per cent. α + arsenious oxide. Cast (unetched). Magnified 150 diameters.
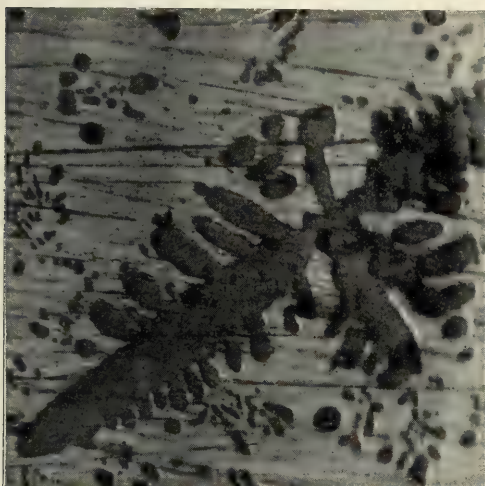
FIG. 9.—Arsenic, 1·8 per cent. α + arsenious oxide. Cast (unetched). Magnified 500 diameters.

FIG. 10.—Arsenic, 1·8 per cent. α + " cores." Cast. Magnified 50 diameters.

FIG. 11.—Bar B10. α segregated + eutectic. Heated to 1000° C. in air. Magnified 50 diameters.
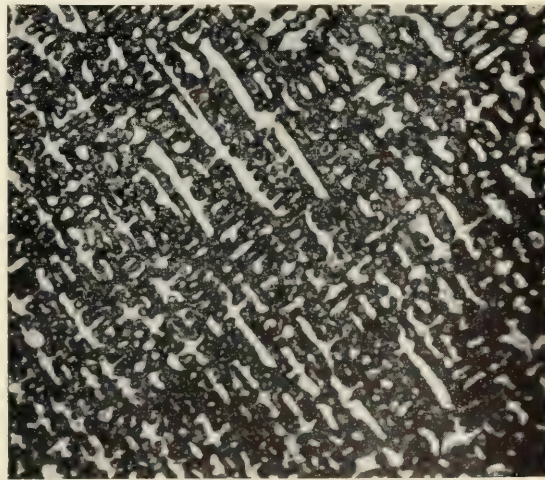
FIG. 12.—Arsenic, 2·5 per cent. S.C. α with " cores." Magnified 50 diameters.

All specimens etched with dilute ammonia.

PLATE III

FIG. 13.—Arsenic, 4·0 per cent. S.C. α with "cores" + β. Magnified 50 diameters.

FIG. 14.—Arsenic, 4·0 per cent. S.C. α with "cores" + β. Magnified 500 diameters.
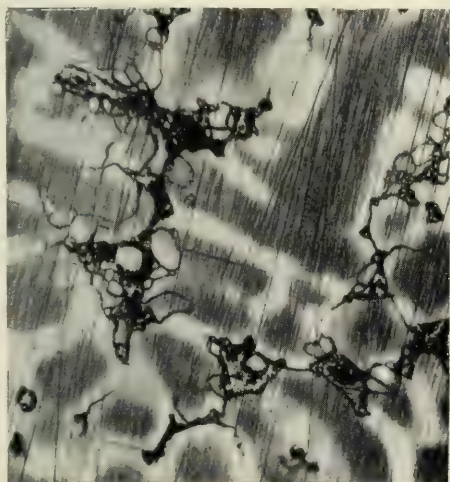
FIG. 15.—Arsenic, 1·3 per cent. Annealed 30 hours at 425° C. α with "cores" + β and cracks. Magnified 50 diameters.
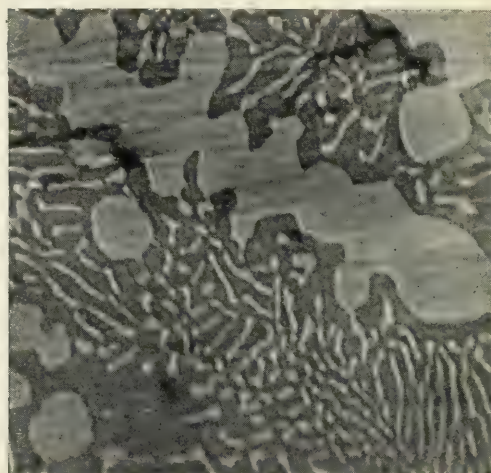
FIG. 16.—Arsenic, 19·0 per cent. Annealed. α + eutectic. Magnified 150 diameters.
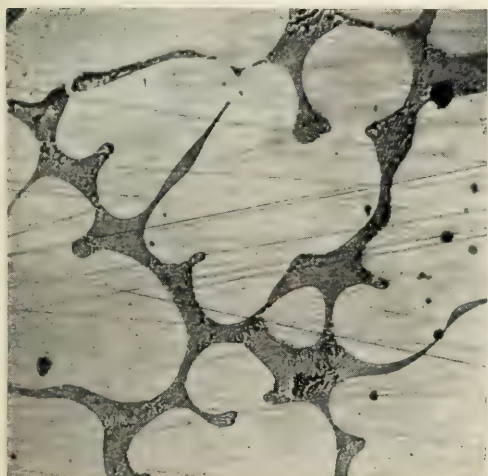
FIG. 17.—Arsenic, 26·9 per cent. S.C. β + eutectic. Magnified 50 diameters.
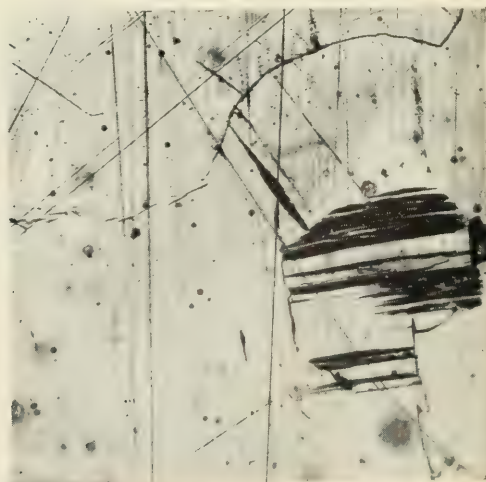
FIG. 18.—Arsenic, 31·8 per cent. Quenched at 730°. γ. Etched with alkaline solution of copper ammonium chloride. Magnified 50 diameters.

All specimens etched with dilute ammonia, unless otherwise stated.

PLATE IV
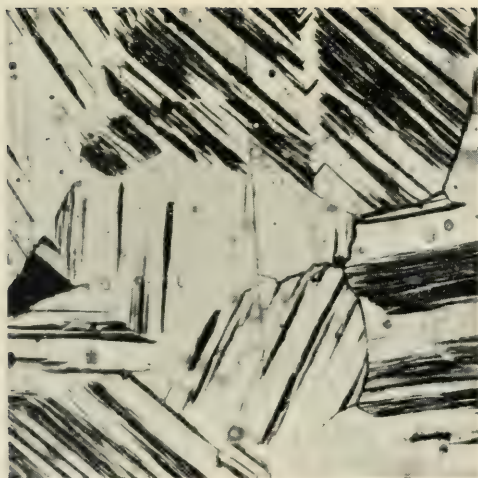
FIG. 19.—Arsenic, 30·8 per cent. S.C. $\gamma + \epsilon$. Magnified 50 diameters.

FIG. 20.—Arsenic, 33·0 per cent. Quenched. $\delta + \eta$. Magnified 190 diameters.

FIG. 21.—Arsenic, 37 per cent. S.C. $(\delta + \eta) +$ eutectic $(\delta + x)$. Magnified 190 diameters.
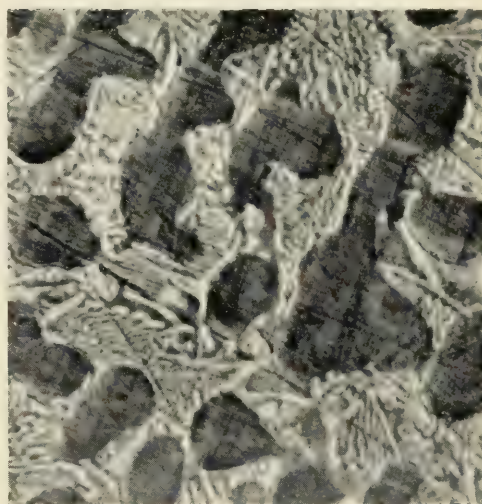
FIG. 22.—Arsenic, 39 per cent. S.C. $\eta +$ eutectic $(\eta + x)$. Magnified 190 diameters.

All specimens etched with alkaline solution of copper ammonium chloride.

arsenic. The large crystals are δ partly broken down to η, embedded in a eutectic of η and an unknown phase x. This specimen has been much more lightly etched than Fig. 20.

Fig. 22 (Plate IV.) shows alloy Y′ containing 39·3 per cent. of arsenic. The large crystals are η.

The last two photos seem clearly to show that the change taking place at 710° is a change in the separated solid. The crystals shown in the last figure are homogeneous, as they have separated at a temperature below the critical tempera-ture 710°, and are homogeneous η, which etches dark. Alloys separating out on the branch of the liquidus just above 710° show crystals which etch dark and light in band-like striæ; the light etching parts are unchanged δ, the dark are parts in which the δ has broken down to η. The breaking down of crystals in the solid into these alternate striæ of different phases is, as far as the authors are aware, an unusual phenomenon.

The last four specimens were etched with alkaline solution of copper-ammonium chloride. The phases δ and η are more readily attacked than γ and ϵ, both by this reagent and by the air. The action of the latter for a few days pro-duced a fine tarnish on δ and η, but not on x, and alloys containing these constituents can be readily photographed without etching. γ alloys did not tarnish sufficiently readily to be photographed in this way. Hence all the alloys in the γ and δ ranges were etched so as to be strictly com-parable.

The authors wish to point out here that it is somewhat doubtful whether a true equilibrium diagram for these alloys containing more than quite small percentages of arsenic can be constructed at all by the ordinarily accepted methods of work. The diagram given in this paper merely gives an idea of the state of things which is to be found in the interior of 250-gramme ingots of the alloys which have been cooled at the rate of 20° C. per minute. Pure equilibrium is not reached under these conditions for the following reasons :—

1. The rate of cooling is too rapid to allow the change in the solid to take place completely at the critical temperatures.

E

2. The rate of cooling is too slow to allow of constancy of composition.

There seems to be no escape from this metallurgical paradox except by carrying out the whole of the experiments in an atmosphere of arsenic vapour, which should be at all times and temperatures in equilibrium with, *i.e.* of similar vapour tension with, the arsenic in the alloy. These conditions could be obtained either by carrying out the experiments in a vessel of constant volume (and gas-tight at all temperatures up to 900° C.), or in a similar vessel whose volume could be adjusted to maintain constant pressure. The system could no longer be considered a "condensed system"; but in addition to the ordinary degrees of freedom usually considered in binary alloys, namely, temperature and concentration, a third would also have to be taken into account, namely, pressure. For an investigation of this kind present experimental methods would require considerable modification.

Section E.—Scleroscope Tests.

The tests with the scleroscope were carried out on the slowly cooled alloys used for the pyrometric work, owing to the difficulty, already noticed, of bringing the alloys to complete equilibrium. Each alloy was embedded in pitch before being tested, and the standard hammer, weighing 2·5 grammes, was used. The results are given in Table IX., and are plotted in Fig. 4.

Since these tests could not be carried out on alloys brought strictly to equilibrium, deductions as to the constitution of the alloys must be drawn with caution. The presence of metastable phases may interfere with the results, and too much reliance should not be placed on them.

Starting from the copper-rich end of the series the curve appears to rise slightly to about 3 per cent. arsenic, corresponding to the limit of solid solution. Between 3 and 11 per cent. the curve seems to run nearly horizontal, and then to rise rapidly to 21 per cent., the eutectic composition. The hardness at the horizontal part is evidently that of the
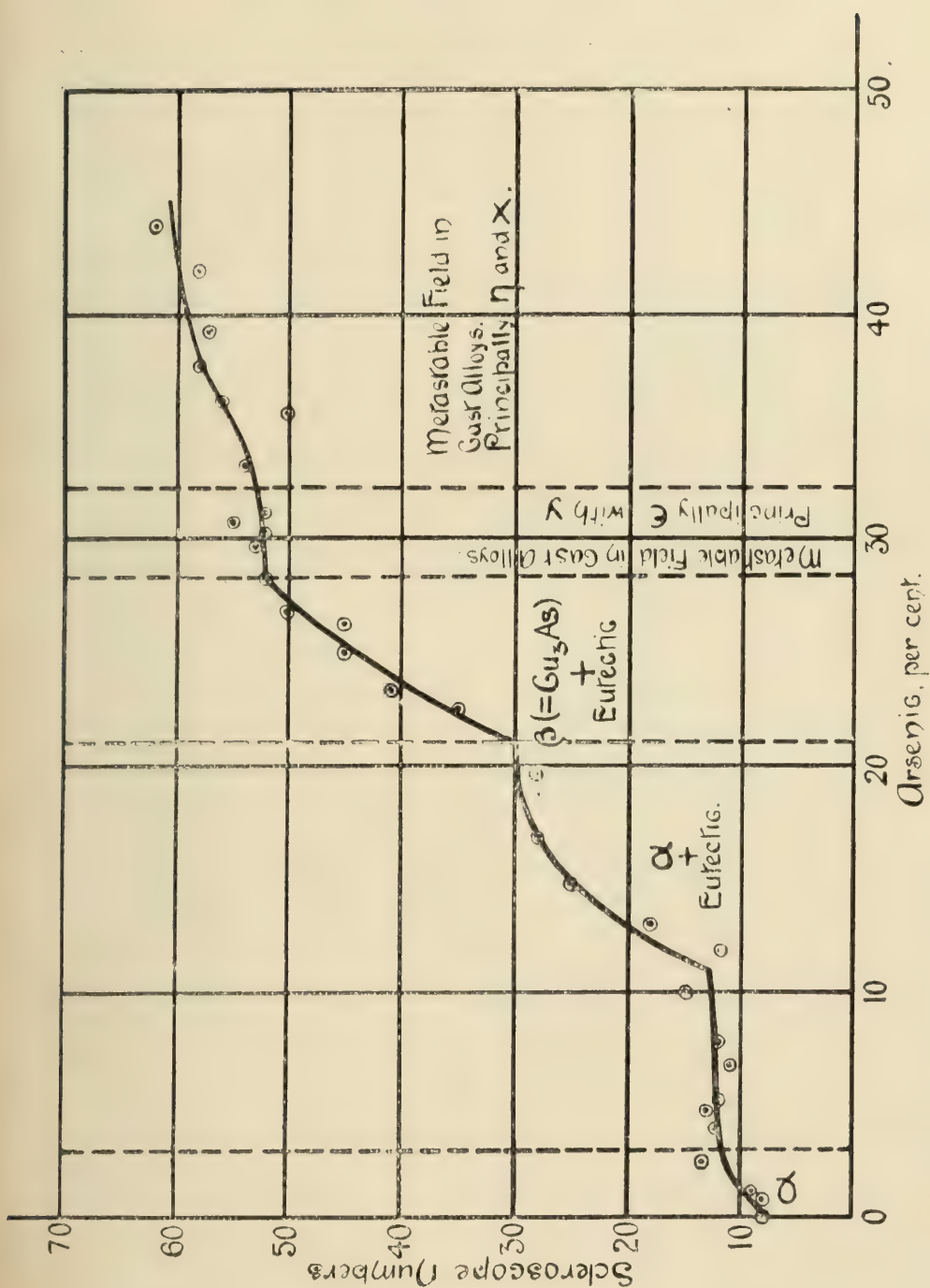
FIG. 4.—Scleroscope Tests on Cast Alloys. (The assignment of the phases refers only to the composition of the cold cast alloys.)

saturated solid solution, and as only small amounts of the β phase are present, and then only as eutectic, it does not appear to affect the scleroscope number very greatly. When, however, the β phase can once assert its effect, the rise in the number is rapid. The break occurring at the eutectic seems natural, since different free constituents are present on each side of it. At 28·3 per cent., corresponding to the compound Cu_3As, a sharp break occurs in the curve, which thereafter becomes practically horizontal over the narrow range of solid solution ending in the compound Cu_5As_2. Evidently the two compounds have nearly the same scleroscopic hardness, as well as similar freezing-points.

Passing the 32·2 per cent. line, the curve rises steadily again owing to the presence of free x and eutectic, and probably at about 50 per cent., the second eutectic composition, it would change its direction again slightly.

The thanks of the authors are due to Messrs. Schuchardt and Schütte for the use of the Shore scleroscope with which these tests were carried out.

TABLE IX.—*Scleroscope Tests.*

Alloy.	Arsenic per Cent.	Scleroscope No.	Alloy.	Arsenic per Cent.	Scleroscope No.
...	0·0	7–8	M′	23·3	41
E	0·9	8	R	25·0	35
F	1·3	9	V	26·3	45
F″	2·5	13·5	N	26·9	50
Q	4·0	12·5	V′	28·3	51
J	4·8	13·0	I′	29·6	53
F′	5·1	12·0	S	30·3	52
O	6·8	11·0	S′	30·8	55
O′	7·8	12·0	X	31·2	52
G′	10·0	15·0	T′	33·4	54
G″	11·7	12·0	T	35·7	50
K‴	13·0	18·0	W	36·3	56
L	14·9	25·0	U	37·8	58
H	16·9	28·0	Y′	39·3	57
M	19·6	28·0	Z	44·0	62
P	22·6	35·0			

SECTION F.—COMPARISON OF THE AUTHORS' DIAGRAM
WITH THAT OF FRIEDRICH.

The authors' determinations of the critical points of these
alloys agree generally very well with those of Friedrich.
They consider, however, that their determination of points
on the liquidus constitute sufficient evidence to prove that
there exists a short and nearly horizontal branch on this
curve between 28 and 32 per cent. of arsenic. Friedrich's
latest work has given several additional points on this part
of the curve, and they lie nearly on a horizontal line. He
prefers, however, to trace through them a very flat, but still
rounded, curve, and gives in consequence one less branch to
his liquidus than do the authors.

In the same range Friedrich considers the horizontal line
at 710° to be a branch of the solidus. The authors, on the
other hand, place the solidus very close to the liquidus, as
shown by the dotted line in the diagram.

Friedrich also considers that the compound Cu_5As_2 cannot
exist above 710° C., and that at that temperature it breaks
down into liquid and Cu_3As. The authors consider that
Cu_5As_2 crystallises out on the liquidus, and that at 710° C.
a change occurs in the already separated solid which gives
rise to the redistribution of energy which is indicated by
the pyrometer. They consider that the microstructure of
these alloys bears out these views. Fig. 21 (Plate IV,) shows
the constituent δ partly changed to η, the change taking
place at 710°. Friedrich admits his inability to account
for the appearance of what he calls "rod-like bodies" in
these alloys. These rod-like bodies, in the authors' view,
are formed by the breaking down at 710° of the Cu_5As_2
crystals. The authors agree with Friedrich in considering
that there is no evidence for the compound Cu_2As proposed
by Hiorns.

Finally, Friedrich gives 4 per cent. as the amount of the
β phase that can be held in solid solution by α. The authors
have shown that the exact amount so held is much influenced
by the rate of cooling, and is, within limits, greater with rapid

cooling.   With the rate adopted in their work the amount was about 3 per cent.   Since Friedrich cooled his alloys more rapidly than the authors, the agreement between the two sets of results on this point is sufficiently satisfactory.

Reviewing the whole of the work on the constitution of these alloys, and bearing in mind that true equilibrium cannot be attained, and that the cooling rates used were different, the authors consider that their own and Friedrich's results are in substantial and satisfactory agreement, the differences between them being confined practically to a range of about 4 per cent.

GENERAL SUMMARY.

1. The mechanical properties of bars containing from 0·04 to 1·9 per cent. of arsenic have been recorded in three states, namely, "as rolled," after being annealed in an oxidising atmosphere, and after being annealed in a reducing atmosphere.

2. Bars containing the larger amount of arsenic were found to be more homogeneous than those containing smaller amounts.

3. The mechanical tests of the bars, both "as rolled" and after treatment in an oxidising atmosphere, were found to be generally satisfactory, except as regards yield-point.   The bars were only "burnt" at temperatures little short of fusion.

4. "Burning" in an oxidising atmosphere was found to be due probably to a structural rearrangement of the constituent of the alloy; the bars were very fragile *at* high temperatures.

5. The bars containing less than 1 per cent. of arsenic were ruined by reducing gases at temperatures above 650° C.

6. One bar, which contained 1·9 per cent. arsenic, was equally unaffected by reducing or oxidising gases, even at high temperatures.

7. This bar was found to be superior in all respects to any of the other bars.

8. A theory has been advanced provisionally to account for the ruin of the bars with less than 1 per cent. arsenic in a reducing atmosphere.

9. Tentative suggestions have been put forward as to the means which might be taken to produce bars which would resist the action of reducing gases.

10. The constitution of copper-arsenic alloys has been considered in detail, and a diagram representing the probable constitution under certain defined conditions has been constructed.

11. The existence of the two compounds Cu_3As and Cu_5As_2, already proposed by Friedrich, has been confirmed. There is no evidence in favour of the existence of the compound Cu_2As.

12. The proposition is put forward, that with the ordinarily accepted methods of work, a true *equilibrium diagram* of these alloys cannot be constructed.

13. The solubility of the β phase in the α phase has been shown to be largely dependent on the rate at which the alloys are cooled ; as ordinarily prepared, these alloys are supersaturated with respect to β.

In conclusion the authors wish to express their thanks to Professor Watkinson for facilities afforded in the Engineering Department of this University.

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APPENDIX.

A NOTE ON THE USES AND LIMITATIONS OF THE "THREAD RECORDER" FOR THERMO-ELECTRIC PYROMETRY.

By GUY D. BENGOUGH, M.A.

THE "Thread Recorder" * is essentially a recording galvanometer, and may be used for recording any energy change which a galvanometer can be made to indicate or measure. The mirror which serves to indicate deflections for an ordinary dead-beat galvanometer of the moving coil type is replaced by a long aluminium pointer, which is attached to the suspension of the galvanometer by a special device. The far end of the pointer, which is some 16 centimetres long, carries an ivory knife-edge. This knife-edge is depressed by clock-work, at known intervals of time, upon an inked thread which is stretched above a cylinder carrying a sheet of squared paper. The depression of the knife-edge presses the inked thread against the paper, and in consequence makes a dot on it; the position of this dot on the paper depends on the deflection of the galvanometer needle at the moment of depression. Consequently, each spot on the paper corresponds to a definite temperature, which can be ascertained by the ordinary methods of calibration. The cylinder carrying the paper can be revolved by clock-work at certain selected rates, and as a result a series of dots will be formed through which a curve may be drawn, the ordinates of which will be time and galvanometer deflections, *i.e.* temperatures.

The instrument described constitutes, of course, a direct-reading instrument; in fact the "chopper bar" which depresses the knife-edge may be graduated in degrees Centigrade, so that an approximate reading of the temperature may be obtained by inspection. The chopper bar is at right angles to the length of the pointer, and extends over the whole of the length of the revolving cylinder.

* Patented by the Cambridge Scientific Instrument Company.

Now it is well known that the mirror (or in this case its equivalent, the pointer) of a galvanometer cannot be very much deflected from its mean position without affecting the suspension and causing changes of zero. Other errors also creep in if a big deflection is put on the moving coil. Hence all direct-reading instruments have a somewhat restricted scale. In the case of this instrument it is only 9 centimetres long.

If this space be divided up into millimetres, each milli-metre may be utilised in either one of two ways:

1. It may be made to represent a small temperature inter-val, say 1°. The whole range of the instrument will then be only 90°.

2. It may be made to represent a large temperature inter-val, say 10°; the range will then be 900°.

In case 1 we have comparatively high sensitiveness, but a restricted range; in case 2 a long range, but low sensitiveness.

Taking case (1) first, the narrow range of 90° may be made to correspond to any part of the temperature interval 0° to 1200° C. by setting up the zero. Thus, suppose the instru-ment is required to read from 445° to 535°. Then the minimum reading of the scale may be made 445° in one of two ways:

The thermo-couple must be brought to 445° by being placed in boiling sulphur, and then torsion must be put on the suspension by means of a nut and key at its top end till the needle comes to rest at one end of the scale. The torsion of the suspension is then exactly balanced by the turning effect of the current set up by the electro-motive force of the couple, when its junctions are maintained at a difference of temperature of 445°. When the thermo junction is allowed to cool down again to the ordinary temperature there will be no current due to the couple, and the torsion of the suspen-sion will exert its effect, and the galvanometer needle will tend to move away off the scale at the low temperature end. It is prevented from doing so by a stop.

Another and more general method of setting up the zero is to ascertain the difference of potential set up in the couple

to be used with the instrument for a difference of 445° be-
tween the hot and cold junctions, and then to maintain that
difference of potential between the two terminals of the
galvanometer, checking the value by a potentiometer; as in
the former method, torsion must then be put on the suspen-
sion to bring the needle to the beginning of the scale.

The writer's instrument has a set up zero at 400° and a
range of 400°.   One would naturally suspect that an instru-
ment that has had its zero set up in this way by putting
torsion on the suspension would show considerable changes of
zero.   During the $2\frac{1}{2}$ years which the instrument has been
in use the zero has shifted to the extent of some 20°, and the
inspection scale readings are too high by that amount.   The
change is in part due to the slow annealing of the suspension
strip; it is a gradual one, so that fairly frequent calibration
will do away very largely with errors from the cause mentioned.

The sensitiveness and range given above have been used
for the work on copper-arsenic alloys carried out by the
writer and Mr. B. P. Hill.   For many of the experiments,
however, a somewhat higher temperature range, namely, from
500° to 1000°, was required.   This could be obtained, but
involved a slightly lower sensitiveness.

The change from one arrangement to the other was made
by the use of what is termed a "multiplying" coil, *i.e.* a
resistance of manganin wire, which can be introduced into the
galvanometer circuit in place of the one originally supplied
with the instrument.

The total resistance of the galvanometer circuit consists in
this instrument of:

      (*a*) The moving coil and suspension.
      (*b*) The rheostat.
      (*c*) The multiplying coil.

Let the resistance of the circuit with no coil be x ohms,
that is, let the resistance of $(a) + (b) = 46$ ohms $= x$ ohms.
If then (c) is made $= 2x = 92$ ohms, then the resistance of the
circuit has been increased to three times its former amount,
and the sensitiveness will have been reduced and the range
increased in approximately the same proportions.   This results

from the fact that the galvanometer deflections are proportional to the current, and $C = \frac{E}{R}$. But E remains constant for a given temperature difference between the hot and cold junctions; if therefore R be increased, the deflections will be decreased in the same proportion.

The change in resistance of the thermo-couple itself is neglected in this statement.

In the author's installation the resistance is $(a) + (b) = 46$ ohms.

	Ohms.
Multiplying Coil (c) has a resistance of	122
,, ,, (d) ,, ,, ,, ...	164

Hence the total resistance in the galvanometer circuit is 168 ohms with the coil (c), and 210 ohms with coil (d).

With coil (c) the range is $400°$, with a sensitiveness of $\frac{400}{90} = 4\cdot4°$ per millimetre. Hence with coil (d) the range will be $400 \times \frac{210}{168} = 500°$, and the sensitiveness will be $4\cdot4 \times \frac{500}{400} = 5\cdot5°$ per millimetre. The zero of the instrument will now be changed from $400°$ to $500°$, and the instrument will read from $500°$ to $1000°$, without alteration of the torsion on the suspension.

If a third coil (e) be used with a resistance of 210 ohms, then the range will be $400 \times \frac{256}{168} = 610°$.

In using a series of coils in this way it must be borne in mind that the scale must be calibrated for each coil, *i.e.* three fixed points of temperature must be determined on the range covered by each coil; also, that similar intervals at the two ends of the scale do not in all cases correspond to precisely similar temperature intervals. For the calibration of the coils mentioned the writer uses:

	Degrees.
For Coil (c) Boiling sulphur	445
Solidifying aluminium	657
The silver-copper eutectic	780
For Coil (d) Solidifying aluminium	657
The silver-copper eutectic	780
Solidifying silver	962
For Coil (e) The silver-copper eutectic	780
Solidifying silver	962
Solidifying copper	1084

It is to be noticed that this principle of using multiplying coils cannot be carried very much further than has been outlined above. In particular, low-resistance coils to give an open scale over low temperature ranges should not be used. This is owing to the variation in the resistance of the couple wires themselves as the temperature rises.

Take the case of a couple 1 metre long, 0·5 millimetre in diameter; its resistance at 0° will be about 2 ohms. At 500° it will be about 3 ohms if the whole length of the couple is heated, or a difference of 1 ohm. Suppose now a multiplying coil of 46 ohms be used; then the total resistance in the galvanometer circuit would be 46 ohms for the coil, 46 ohms for the suspension, and 2 ohms for the couple at 0—in all 94 ohms. A variation of 1 ohm on this gives rise to a 1 per cent. error. In practice the error would be somewhat less than this, since the whole couple would not be heated. For works' purpose, where one recorder might be used in connection with several couples connected by leads of various lengths, very low resistance coils should also be excluded.

On the other hand, very high resistance coils are not altogether satisfactory, since when they are used equal intervals on the scale correspond to rather widely differing temperature intervals. Even coil (e) is not very satisfactory in this respect.

When several coils are used it is convenient to have a wire brought from the galvometer to a buss bar fixed outside the case of the instrument. By means of a plug, connection can then be readily made between the bar and any one of several resistance coils which are connected to separate grooved brass sections.

For the purposes of recording the temperature of annealing furnaces the writer has found it very convenient to use an automatic rock-over switch, by means of which records are obtained alternately for two furnaces for periods of five minutes each. By joining up the broken curves thus obtained satisfactory approximations to continuous curves can be got from two furnaces simultaneously.

The switch used for this purpose was made in the laboratory, at a cost of a shilling or two, in the following way. The

face and hands of a shilling American clock were removed, and in place of the hour-hand a sheet-brass wheel about 1 inch in diameter was fixed. This had six brass projections arranged at equal intervals round its circumstances. The wheel itself was in connection with the + pole of a storage cell. The projections periodically came into contact with one or other of two bent springs, opposite each of which was a platinum-tipped screw adjustable through a pillar. Each spring alternately was pushed back by the projections so as to make contact with one or other of the platinum-tipped screws. When this happened the battery circuit was completed through one of two electric magnets. To secure this the + pole of the battery circuit was connected to the rotating wheel, and the negative pole to a binding screw, which was connected to one end of the windings of both the electro-magnets. The other ends of the magnet windings were brought back to the platinum-tipped screws, one to each screw.

The magnets were fixed on each side of a lump of paraffin wax, in which were six mercury cups arranged in three pairs. To the middle pair were brought leads from the galvano-meter. To each end pair were brought the leads from one or other of the two thermo-couples whose indications were to be recorded. In the middle cups were also plunged two copper bars joined together, but electrically insulated from each other by a strip of vulcanite. This vulcanite also carried two iron projections which came opposite the electro-magnets. When one of the magnets was excited by a current, it attracted the iron and caused a slight rotation about the ends of the copper bars as fixed points. To each copper bar was also attached a semicircular copper hoop, bent so that its ends could dip into either of the end cups when the magnet attracted the rotator in that particular direction. Thus when the ends of the hoops were dipped in the cups at one end, the other ends were just clear of their cups at the other end of the paraffin slab. The current from the couple attached to the cups in which the two hoop limbs were dipping then passed from one of the cups, along the copper hoop to a centre cup, thence to the galvanometer, back to the other centre

cup, through the other copper hoop to its cup, and so back
to the couple. The rotator will remain in that position for
five minutes. At the end of that time the current will
be switched through the other magnet, and the hoops
will be pulled over to make contact with the other two
mercury cups.

With regard to the accuracy of this pyrometer as used in
the research of copper-arsenic alloys, with the coil (*a*) referred
to earlier the temperature can be estimated from the paper
records to about 3°. In the following table the two columns
give the temperature estimated from the records, and the same
temperature measured by the Carpenter-Stansfield potentio-
meter. The temperatures given in the recorder column are
the temperatures at which the first obvious change in direction
of the cooling curves took place, both in the case of freezing
points and inversion points. In the case of the potentio-
meter the temperatures of the maximum rates of inversion
have been taken.

Recorder. Degrees C.	Potentiometer. Degrees C.	Recorder. Degrees C.	Potentiometer. Degrees C.
830	830	690	685
805	807	685	685
750	755	600	601
708	705	600	600
708	708	303*	303
705	707	306*	302

Considering that the potentiometer may be regarded as a
standard method for accurate work on alloys, the agreement
is quite satisfactory, and is better than was expected by the
author; in cases where differences occur, the readings of the
potentiometer are, of course, to be preferred.

It is to be noticed in this connection that the heat evolu-
tions accompanying the inversions in copper-arsenic alloys are
considerable, and much greater than occur in some other
series of alloys. Also relatively large amounts of the alloys
were used (250 grammes). The conditions therefore have
been favourable to an instrument of comparatively low sensi-
bility. Nevertheless the ease of manipulation and the advan-
tages that accrue from the partial elimination of the personal
element seem to the writer to entitle a direct-reading instru-

* Mercury thermometer.

ment of this type to be regarded as very useful for a large number of purposes. For instance, it will give a very good idea of the form of the liquidus of any series of alloys, and it is sufficiently accurate and is very useful for the recording of annealing furnaces temperatures, especially when these have to be determined over long periods of time—the clocks usually only require winding once every twelve hours. For measuring flue and blast temperatures it is amply sensitive. For the measurement of inversion temperatures its use is limited to cases accompanied by large heat evolutions.

The weak point about the instrument is the length of the indicating needle, which causes it to vibrate considerably. This vibration is, however, principally vertical, and does not introduce such large errors as might be imagined. To reduce them as far as possible the instrument must be set up on a brick pillar with a good foundation, or on a bracket attached to a solid main wall, and as far as possible from such sources of vibration as passing carts, &c.

DISCUSSION.

Mr. BENGOUGH said that, with the permission of the President, he desired to give some additional information and explanations. With regard to the composition of the copper-arsenic alloys actually in use, he desired to remind the members that a Committee of the International Association of Testing Materials was sitting to consider the specifications which might be usefully adopted for copper. Mons. Guillet was the President, and the English representatives were Dr. Glazebrook of the National Physical Laboratory and Mr. Tomlinson of the Broughton Copper Company, one of the members of the Institute. A first report had been issued, containing a résumé of current specifications for copper alloys containing only small quantities of the second element, and some of them were copper-arsenic alloys. The extended specifications were in the *Revue de Métallurgie*, December 1909. The alloys which were specified for copper wire for electrical purposes must contain less impurities, including arsenic, than 0·04, *i.e.* they must be purer than the purest bar which had been used in the research. With regard to the copper sheets for locomotive fire-boxes, the committee gave a typical specification as adopted by the Engineering Standards Committee. For Class A alloys, arsenic above 0·35 per cent. and less than 0·55 per cent. could be used, but the copper must be over 99 per cent. In Class B alloy the arsenic could be over 0·25 and less than 0·45 per cent., and the copper over 99·25 per cent. The North-Eastern Railway specified arsenic over 0·2 and less than 0·5, and the German and French railways excluded arsenic altogether. The tensile tests for the alloys were maximum stress 14 tons, and elongation 35 per cent. In both the specifications of the Engineering Standards Committee and the North-Eastern Railway the bending test was that the alloys were to be bent double cold without crack or flaw. In the German railways the alloys had to be bent hot or cold round a mandril in diameter twice the thickness of the plate. The specifications for stays for fire-boxes and for tubes were practically identical with those for the plates, with a few additional tests. The experiments described in the paper went to show that the percentage of arsenic might possibly be increased beyond the figures given in the above specifications, which were those usually employed. The arsenic seemed to give improved properties, but he was not quite sure whether the higher arsenic alloys would stand the bending tests in the specification to which he had referred. With regard to the serious effect of reducing gases on these alloys, it seemed rather remarkable at first sight that the life of fire-box metal was not very much shorter than it was, and that more frequent failures did not occur, especially when it was remembered that in practice the gases in locomotive fire-boxes frequently contained a considerable amount of carbon monoxide—up to 3 or 4 per cent.—especially at slow train speeds, as had been shown by Dr. Brislee in his paper in the *Proceedings of the Institution of Mechanical Engineers*, March 1908. The explanation seemed to be found in the fact that the temperature of the metal even at the fire-box surface seldom rose to the temperature (about 650° C.) required

for the reaction between the gas and oxide. Webb * had shown that the temperature of the stays $\frac{1}{2}$ inch from the furnace end was only 200° C., but at the end of the stays inside the fire-box the temperature might rise to 615° C., *i.e.* to the danger zone. As a result one would only expect cracks at the ends of the stays and on the surface of the fire-box plates. Law, in his book on alloys, mentions that it is no uncommon thing to see the inner surface of the copper plates showing drops of copper where the metal had actually melted, and in that case one would expect the destructive action of the reducing gases to penetrate deeper into the plate. If cracks were formed, even on the surface, the life of the fire-box metal was bound to be considerably shortened. A recent tendency seemed to be to use cupro-manganese for fire-box stays, particularly in France, and Law quotes statistics of their behaviour in practice. He hoped on a future occasion to carry out an investigation on those alloys if he could obtain a supply of them.

Leaving the question of fire-box metal for the moment, several other interesting points presented themselves in connection with the alloys that had been used for the study of the constitution. One of those was the very different effect exercised by the arsenic on the electrical conductivity and on the tensile strength of copper. Mr. Hill and himself were not able to give at present a physical explanation of the difference. There was, however, one very peculiar form in which the Cu_3As might apparently crystallise out to which no reference had been made in the paper: it was illustrated in Plate I., Figs. 5 and 6. It would be noticed that those figures showed apparently broad slip bands or areas occupied by amorphous material. Those specimens, however, had been annealed for three hours at 800° C., and similar specimens presented a practically identical appearance, even after annealing for forty hours at 700° C. in either an oxidising or reducing atmosphere. It was evident, therefore, that those striæ were not slip bands or amorphous material, both of which would disappear under such treatment, and a very interesting question arose as to their nature. He believed them to be striæ of Cu_3As which had crystallised out from the supersaturated solution, during annealing, along the plane of weakness exhibited by the loci of old slip bands which had been imperfectly healed up. In other words, those striæ were pseudo-morphs in Cu_3As after the slip bands. The authors had shown that this alloy, bar B, must be supersaturated with Cu_3As, which, with annealing, would slowly crystallise out. In a solid alloy it would crystallise out in those parts of the alloy which would give least resistance to it. At the beginning of the crystallising out process the slip bands which had been produced before the annealing process would still be planes of weakness, and preferentially the Cu_3As would separate out at those particular parts of the alloy. That was what the speaker believed those very remarkable structures to be. It was important to bear in mind that the arsenic might be present in the alloy in three different states. First of all, it might be present in the commercial alloys as Cu_3As separated out. Most of the commercial alloys showed some

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* *Proceedings of the Institution of Civil Engineers*, 1901–2.

traces of this compound here and there as widely separated particles.   In the second place, the main part of the arsenic in ordinary commercially-prepared alloys remained in solution as Cu_3As, and only annealing enabled that to crystallise out further.   In the third place, arsenic might to a certain extent act as a deoxidiser, and in that case some of the arsenic would be present in the alloy as scattered particles of arsenious oxide.   In any given alloy the arsenic might be present as either one, two, or all three of the forms he had mentioned, and its effect might be very different in the several cases.   As oxide it affected mainly the conductivity, but not the tensile strength to any great extent.   If it crystallised out from solid solution in masses as Cu_3As it seemed bound to spoil the ductility, although that had not been put to rigid experimental test. The only other point that called for comment in connection with Part I. of the paper was that arsenic distinctly raised the temperature at which copper was burnt in an oxidising atmosphere, as shown by bars B12 and A10.   In regard to Part II., he wished to apologise for the scratches which appeared on several of the photos.   The present meeting had taken place rather sooner than the authors had expected, and they had been rather pressed for time in finishing off their work.   It became a question as to whether they should hold back the paper until next October in order to eliminate those scratches, or publish the photos as they were.   As a matter of fact several of the photos were taken merely as records and for their own study, and were never intended at all for publication.   The authors, however, had decided, as the structures in all cases were clear and not interfered with by the scratches, to publish them as they were rather than delay publication for so long a period.

Professor A. K. HUNTINGTON, Vice-President, said that whilst listening to the author he had endeavoured to recall the results of some work he had done some years ago on this subject, and one or two facts had come back to his memory which possibly might be of some interest to the members. The paper was an exceedingly valuable one, for which the members were much indebted to the authors.   It was just the kind of paper the Institute required ; it showed a great deal of care, thought, and a lot of work, and it would be impossible to have too many papers of such a kind.   He hoped, therefore, the members would not think that in making his remarks he wished to detract from the value of the paper ; the authors had very carefully worked on the subject.   The first point that struck him was the remark made in the general introduction : "The reasons for using an arsenic alloy instead of pure copper are, firstly, to secure greater strength and rigidity, particularly at high temperatures ; and, secondly, to secure an alloy that shall resist the action of flames—that is, of gases at high temperatures."   He wished to entirely disagree with that statement.   Arsenic did not give copper good working properties at high temperatures ; quite the contrary.   He thought arsenic was highly detrimental to copper at high temperatures.   The statement the authors had made to which he had referred had no bearing on the work mentioned

in the paper afterwards; there was no reference in the paper to the *strength* of copper at high temperatures, but only to the action of certain gases on copper at high temperatures, the copper subsequently being tested cold, which was a totally different matter. He thought it right, however, to call attention to the statement, because as it appeared in the general introduction it was not correct. On page 51 the authors stated that the fifth conclusion at which they had arrived was, "The actual cause of the ruin of the alloy seems to be a sudden evolution, and subsequent expansion, of steam or carbon dioxide, formed as a result of the reaction between hydrogen or carbon monoxide and arsenious oxide in the interior of the mass of metal; the gases resulting from the reaction are probably insoluble, or only very slightly soluble, in solid copper; hence their destructive reaction." He did not think that statement was borne out by the facts given in the paper itself, because on turning back to page 49 it would be found that the authors made an experiment with reducing gases on copper containing oxide of copper, and it was not found that those reducing gases had the effect which was subsequently produced when oxide of arsenic was there. It would be a somewhat strange thing that the reducing gases should have no effect on a copper containing oxide, which was the normal copper used in commerce, and yet the moment arsenic was introduced and arsenious oxide was formed subsequent treatment with a reducing gas should cause such expansion as to ruin the metal. That to his mind was not a tenable position, and he did not think it was the case. He had looked up some notes whilst in the room and found that in January 1906 he made some experiments on copper containing arsenic. 0·5 per cent. of arsenic and electrolytic copper of a very pure character were used; they were melted under borax, and cast into a mould. He had the photographs with him, which were taken at 80 and 320 diameters, and he would be happy to show them to those members who cared to see them (Figs. 5 and 6). He also made another experiment, in which he used granulated copper mixed with copper arsenate and fused under glass. The conclusion he came to as the result of these and other experiments that were made at the time was that a definite arsenite of copper was obtained—a compound of copper oxide with arsenious acid. It was his belief at the time that he obtained a definite arsenite of copper which was dissolved in the copper just as oxide of copper dissolved in copper when it was molten, and which subsequently on cooling separated out all round the crystals of copper. It was obvious that those oxides would be reduced by the reducing gases, and would leave planes of weakness all round the crystals, which was precisely what was found in the illustrations given by the authors. For instance, in Plate II, Fig. 7, there was what was called a complete " shattering of the structure of the metal "; there were sharp lines all round the crystals, which was precisely what was to be expected; and exactly the same thing occurred owing to reduction of material exuded round the crystals, as shown in the photo-micrographs he (Professor Huntington) had brought. He remembered distinctly that the arsenite did not come out clean all round the crystals, but penetrated for some dis-
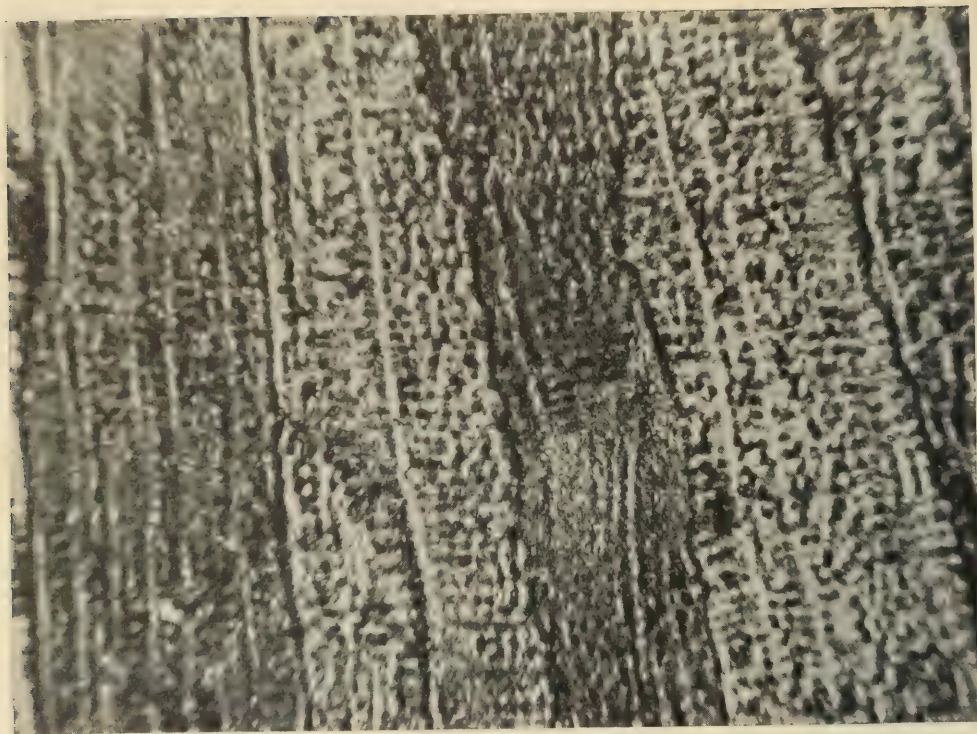
FIG. 5.—Electrolytic Copper fused with 0·5 per cent. Arsenic and then allowed to absorb Oxygen. Etched Electrolytically in very dilute Nitric Acid. Oblique illumination. Magnification, 80 diameters.
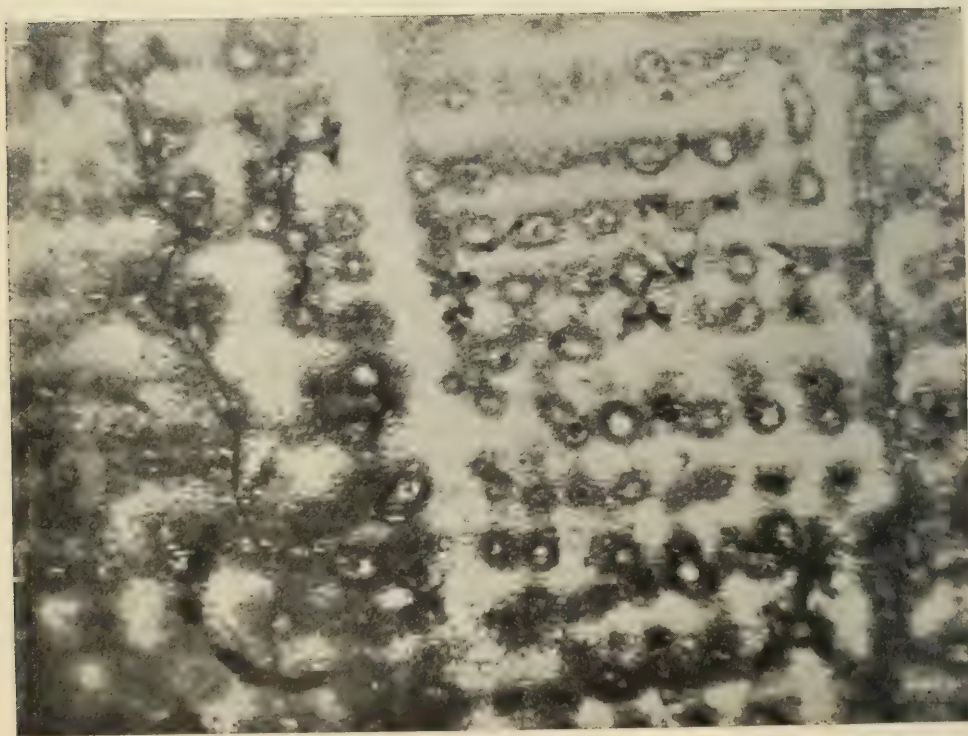

FIG. 6.—The above Illuminated Vertically. Magnification, 320 diameters.

tance into the crystals themselves; probably if the cooling had been slower it would have segregated entirely between the crystals. He had no wish to dogmatise about the existence of this arsenite, or to assert that what he had stated was absolutely the case, but that was the impression he obtained from the work he carried out at the time, and the probabilities appeared to him to be in favour of this view.

Dr. W. ROSENHAIN (Teddington) desired first of all to join with Professor Huntington in his appreciation of the paper. He had very seldom so much enjoyed reading a paper as he had done the present one, because both in what it did and the way it did it, it was a particularly good example of work of its kind. He made those remarks to begin with because there were one or two points in the paper which he did not wish to criticise, but to comment upon. Mr. Bengough had referred to the International Committee on Copper Specifications. He (Dr. Rosenhain) had the honour of being a member of that committee at the Copenhagen Congress, where the question of arsenic in copper was very carefully discussed, and the French and German representatives, although the specifications which they had quoted as typical of their countries did not allow the introduction of arsenic, were quite prepared to accept the necessity of arsenic appearing in locomotive fire-box plates. With regard to the question of raising the limit of arsenic in the specification, he considered that further evidence should be adduced other than the authors' results before that could be accepted. First of all, as the authors pointed out, the question of the bend tests had to be taken into consideration, and in addition to that it was necessary to know something about the fatigue and shock resistance of materials containing arsenic. The authors' results were based purely on tensile tests; and although they were very valuable, they did not tell everything or enough about the properties of the materials. Nevertheless the results as far as they went tended to remove the prejudice against high arsenic above $\frac{1}{2}$ per cent. With regard to the paper itself, the authors described non-homogeneity as a characteristic of the lower arsenic alloys of the series. Considering that the experiments which had been made referred to only one ingot of each copper alloy, were the experiments really sufficient to justify such a sweeping conclusion? Personally he thought it would be necessary to get a considerable number of ingots, and see whether the non-homogeneity was produced in them all. With regard to the cracks to which Professor Huntington had referred, the explanation offered in the paper made it difficult to understand why the explosion should occur in the inter-crystal boundaries rather than in the body of the crystals themselves, and from that point of view the arsenite theory of Professor Huntington appealed to him very forcibly. With regard to the question of the striæ structure, he was very much interested in Mr. Bengough's explanation that they were pseudo-morphs of the traces of the slip bands. He thought perhaps Mr. Bengough was wrong in saying that the planes were initially planes of weakness, but rather during the process of slip there was a formation of amorphous phase which, when it came to be annealed, underwent a

molecular rearrangement, and during that rearrangement it was particularly free to undergo chemical changes. An exactly similar case had been found in nickel steels somewhat high in nickel. Pure gamma iron steels when deformed underwent decomposition along the lines of slip. He thought he could give Mr. Bengough a reference to an old paper of his (Dr. Rosenhain's) in which that was clearly demonstrated. It was interesting to find that that kind of thing apparently went on frequently. It was rather like scratching a beaker with a glass rod when the beaker contained a supersaturated solution ; the solution tended to crystallise at the place where there had been mechanical disturbance. Finally, he thought there was a slight mistake on page 60 of the paper, where the statement was made, " The phase α can hold about 3 per cent. of β in solid solution at the ordinary temperature." Should not that be 3 per cent. of arsenic, as on page 61, or if β was Cu_3As, containing 28·3 per cent. arsenic (not copper), it might read—" 9·4 per cent. of β." As it was, the statements on the two pages were not quite in agreement.

Mr. E. L. RHEAD (Manchester) wished to join with the previous speakers in congratulating the authors on the very valuable paper they had presented to the Institute. He desired to call attention to one point that had been raised by Professor Huntington with regard to the effect of small quantities of arsenic. Two or three years ago he did some work on electrolytic copper and arsenic, and prepared a series of alloys containing 0·5, 1·0, and 1·5 respectively of arsenic. It was found that even with the 0·5 per cent. of arsenic segregation occurred, and that on the borders and the angles of the crystals distinct separations of an arsenical compound took place. Whether the authors had noticed that in connection with any of their lower arsenic alloys he could not say, but in his case it was repeated several times, and it was found that it applied not only to arsenic, but also to antimony as well, the two substances being more or less chemically similar. He further wished to point out that, with regard to the interpretation of some of the crystallographic effects brought out by the microscope, that he had obtained identical results with those shown in Plate II., Fig. 9, by the addition of antimony to metallic manganese, a case in which it was impossible for any oxidisation effect to have occurred in the crystallised substance or antimony.* The two substances crystallised in the same form, and as a consequence by inference he thought it might be considered that the crystals were something with an hexagonal form, and not a form in which arsenious oxide usually occurred. It would be noted that a similar separation occurred in Plate II., Fig. 8 ; if the crystallisation was not arsenic, it was probably a metallic arsenical body. The question of the rearrangement of substances along the slip bands had been admirably dealt with, but he wished to add the suggestion that possibly the production of the bars was due to recrystallisation in a direction differing from that occupied in the original crystal so as to give the

* [See Fig. 7, p. 87, and Fig. 8, p. 88.—*Ed.*]

effect of twinning. That was constantly met with in mineralogical work. It did not necessarily mean an alteration in composition, but merely a different disposition of the same substance with regard to the original crystal. It would produce definite bands exactly as shown in the diagrams. The only other point to which he wished to refer was, that he had on two occasions obtained definite evidence of the fact that arsenical copper alloys were very seriously corroded by gases containing chlorine, and that the gases from coal fires frequently contained that constituent in small quantities. The nature of the attack was evidently that of attacking the arsenical compound and removing it, probably as a highly volatile chloride of arsenic, and thus opening up the structure
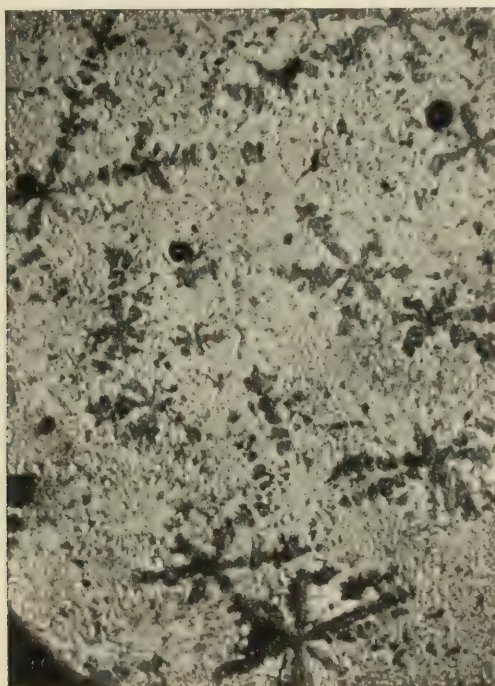
Fig. 7.—Metallic Crystals. Magnification, 150 diameters.

of the metal to serious attack by the other constituents of the gases. He also wished to mention that at the first Birmingham meeting he called attention to the very curious effect produced by heating ordinary copper for long periods in reducing gases. Figures had been obtained identical with Plate I., Fig. 2, and it was considered by many that the reduction of the oxides in the metal was the cause of the cracked appearance that was produced under that treatment. The copper that was used for the purpose was not highly arsenical copper; it was the copper ordinarily employed for making soldering irons, and it was in connection with those tools that the appearance was first obtained. Heated in charcoal so that the air could penetrate alongside the tool, there being sufficient separation for that to take place when the iron was

pushed into the fire, the metal was heated under oxidising influences, but when heated in a gas fire, such as was frequently now employed, the metal was subjected to those reducing conditions, and the "gassed" effect, as it was technically known, was produced.
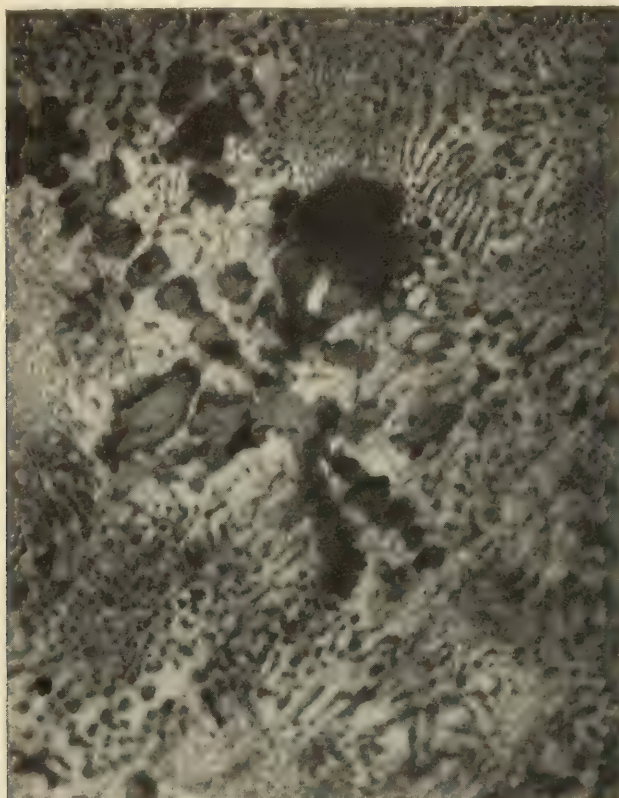
FIG. 8.—Metallic Crystals and Eutectic Structure.
Magnification, 1050 diameters.

The PRESIDENT invited any other members who wished to take part in the discussion to send their remarks in writing, so that they might be published in the Journal.

Mr. BENGOUGH, in reply, said he would communicate the bulk of his reply in writing, and only at the present moment reply to the question which had arisen as to the reaction which took place between the oxide and the reducing gases. The authors took into account the possibility of a phase crystallising out in the way indicated by Professor Huntington They found, however, there was one fact very strongly against this explanation being sufficient by itself, namely, that there was a critical temperature at which the destructive action took place. In simply crystallising out from solid solution, surely there would not be any critical temperature at which that action would take place. For instance, the action might take place slowly if the metal was heated

for a long time at a low temperature, and more quickly after a short time at a high temperature. The authors found, however, that in no case did the reaction take place below 600°. There was a definite critical temperature below which the reaction did not take place. That fact they thought told strongly in favour of some chemical reaction, in addition perhaps to a purely physical change.

Professor HUNTINGTON inquired whether that would not be the temperature at which the oxide was reduced. When the reducing gases were applied the oxide was reduced, and of course the bulk of the material in the interstices was reduced and the attachment of the crystals to one another weakened. The photograph he showed was of an alloy containing 0·5 per cent. of arsenic. It was a very curious photograph, showing the action of the gas on the segregated matter between the crystals.

Mr. BENGOUGH said that he did not in the first instance quite understand Professor Huntington's explanation, but that gentleman had now made it clear. With the President's permission he would reply to the remainder of the discussion in writing.

The PRESIDENT thought the discussion which had taken place fully confirmed the remarks he made in his Presidential Address as to the number of vistas of knowledge that were opened up on any subject that was dealt with. The discussion on the paper had started half-a-dozen different lines of thought, on each of which he could speak for half-an-hour, and on which any one of the members could spend a month in investigation.

COMMUNICATIONS.

Mr. L. ARCHBUTT, F.I.C. (Derby), wrote that he thought if the authors had determined the oxygen in the copper bars which were heated in reducing gases, the results obtained would have been easily explained. It would probably have been found that all the bars except B (1·9 per cent. arsenic) contained oxygen, and it was important that the amount of oxygen present should be known, on account of the bearing it might have upon the mechanical properties. In a paper read before the Society of Public Analysts in December 1905,[*] he (the writer) showed that the whole of the oxygen could be removed from a bar of copper ½ inch in diameter by heating it to redness in hydrogen for several hours, and that the effect of this was to render the copper extremely brittle, and to cause it to expand considerably and become fissured by cracks which passed between the crystalline grains. Those grains increased in size

* *The Analyst*, 1905, vol. xxx. p. 385.

as the result of the heating, and the junctions between them became loosened. It was, therefore, not surprising that the copper became very brittle, nor was it, he thought, surprising that the oxygen became gradually burnt out from the interior of a thick piece of copper. All the results recorded in his (the writer's) paper were obtained with arsenical copper, but the same results were obtained with copper free from arsenic. He had in his possession a piece of hammered copper which was originally about $1\frac{3}{8}$ inch long and of about $\frac{1}{4}$ inch to $\frac{5}{16}$ inch square section. It contained 0·524 per cent. of oxygen ($= 4·688$ per cent. Cu_2O), and no arsenic. By heating it to a full red heat in a current of purified hydrogen for two hours all the oxygen was removed, and the bar split open in a longitudinal direction, numerous fissures being formed between the laminæ produced by the hammering. The authors were, therefore, quite mistaken in supposing cuprous oxide to be harmless ; the cuprous oxide was, in fact, the constituent which caused the mischief when copper became " gassed," *i.e.* exposed at a red heat to the action of reducing gases. Pure copper free from oxygen could be heated to redness in hydrogen without any loss of ductility.

Professor H. C. H. CARPENTER, Vice-President, wrote expressing his appreciation of Messrs. Bengough and Hill's paper. The research was valuable, both from a practical and scientific standpoint ; and he wished to compliment the authors on the way they had met, and to some extent overcome, its difficulties.

In view of the use of copper-arsenic alloys containing small amounts of arsenic for locomotive fire-box stays, it would have been interesting if the authors had supplemented their tensile tests at ordinary temperatures with others at temperatures likely to be reached in working practice. If such data could be given for the alloy containing 1·9 per cent. of arsenic, they would increase the value of the paper.

The authors had found that the alloy with the best mechanical properties, and possessing the greatest resistance to the action of oxidising and reducing gases, was one containing 1·9 per cent. of arsenic. On p. 47 they pointed out its similarity as regards tensile tests with a copper-aluminium alloy containing 2·1 per cent. of aluminium, described by the writer and Mr. Edwards in the Eighth Report of the Alloys Research Committee of the Institution of Mechanical Engineers. This parallelism was not unimportant. It might be worth instituting comparative static and dynamic stress tests between these two alloys to determine which was superior for fire-box stays. The aluminium alloy possessed the advantage that it was easy to prepare of the exact composition owing to the non-volatility of aluminium at the temperature of manufacture. The alloy was homogeneous, and any aluminium oxide it might contain would be unaffected by reducing gases. The writer would gladly furnish Mr. Bengough with specimens of the aluminium alloy if he would care to undertake the tests.

He had been much interested in the authors' theory of the cause of the ruin of bars containing less than 1 per cent. of arsenic in the pre-

sence of reducing gases at temperatures above 650° C., viz. (p. 51) " the sudden evolution and subsequent expansion of steam or carbon dioxide, formed as a result of the reaction between hydrogen or carbon monoxide and arsenious oxide in the interior of the mass of metal."

If this was the correct explanation, it seemed difficult to explain why copper containing copper oxide was quite indifferent under this treatment, as the authors had shown. It would certainly be reduced, and the same gases formed. Was it possible that the cause of ruin was a reaction between the reducing gases and a copper arsenite, resulting in the formation of a copper arsenide, and the setting up of stresses consequent on its formation and possible tendency to dissolve in the copper. Insoluble gases might still play a part similar to that conceived by the authors.

The peculiar and interesting difficulties attending the determination of the equilibrium diagram were well stated (pp. 65 and 66), and the authors were to be complimented on having clearly stated the limitations of their own diagram. In spite of these limitations it was of definite scientific and practical value. The elucidation of the structures of the phases of alloys, containing between 28 and 32 per cent. of arsenic, had presented special difficulties, owing to their sensitiveness to the slightest mechanical stress.

As regards the dependence of the solubility of the β- in the α-phase on the rate of cooling, the copper-aluminium alloys present a direct contrast to those of copper and arsenic. With ordinary rates of cooling the β-phase appears at about 8 per cent. of aluminium, whereas if the cooling is sufficiently retarded to allow equilibrium to be reached, the β-phase only appears at about 9·5 per cent. of aluminium, *i.e.* with ordinary rates of cooling the alloys are unsaturated with respect to β.

He regarded the research as one of the most valuable that had been presented to the Institute, and hoped that its extension foreshadowed on p. 52 would yield equally important results.

Mr. O. F. HUDSON, M.Sc. (Birmingham), wrote that he had read Messrs. Bengough and Hill's paper with much interest. It contained a concise record of a series of skilfully conducted experiments, followed by carefully reasoned conclusions, and it was one that should have a very direct and useful practical bearing. That part of the paper which dealt with the annealing of arsenical coppers was of very great importance, and threw much light on the general question of the "burning" of metals and alloys. It seemed quite clear that the size and growth of crystals were insufficient in themselves to account for the complete destruction of all useful properties ; the cause must be sought in some irreversible change that leads to the formation of an injurious constituent or a disruption of the crystalline structure. That such was the cause of the burning of these alloys in reducing gases seemed well proved, and that arsenious oxide should have such an injurious effect under those conditions, while cuprous oxide by itself was harmless, or comparatively so, seemed to him to be somewhat surprising. From the evidence adduced, however, there appeared to be no reason to doubt the authors' conclu-

sions, and the results of their work served to emphasise the importance of the part that gases might play in annealing operations.

Mr. F. JOHNSON, B.Sc. (Birmingham), wrote that the work carried out by Messrs. Bengough and Hill fell categorically into two parts, one being of a practical nature, the other theoretical. That was an admirable classification, and one which must appeal greatly to all members of the Institute. It was of much importance for all those who would refer to that work in future to be guided immediately into the particular section containing the information which they sought.

The authors had done much in the first part to establish, by useful practical tests, facts which, although they had mostly been recognised for some years amongst manufacturers and experts engaged in the production of copper-arsenic alloys, yet had worn a disputable and controversial aspect amongst engineers and general metallurgists.

In Part I. of the research, the first point which occurred to the writer was that the authors had used bars made from copper and *metallic* arsenic. The latter had the effect of conferring greater strength upon copper tested at ordinary temperatures than arsenious oxide, which hardly affected its strength at all.* It would be most interesting to learn how the authors' bars A to E would behave if submitted to a systematic series of tests, static and dynamic, at high temperatures.

The analyses showed that in those bars copper had not been determined, but had been taken by difference. That was quite unsatisfactory, in view of the property which copper possessed of dissolving oxygen and of clinging tenaciously to traces of that element, even after such treatment as it received in melting as described by the authors. In the writer's opinion, copper and oxygen should both have been determined, especially in the case of the bars ruined by heat treatment in a reducing atmosphere. It would have furnished one more link in the chain of evidence showing that the direct cause of deterioration of the bars was the abstraction of oxygen.

It would be interesting to know the exact treatment which the copper received in melting, since molten copper had the property of dissolving gases of a reducing nature, particularly carbon monoxide and hydrogen, and if there were insufficient oxygen or arsenic present to check that solvent action, a cast bar would be porous, due to the evolution of the gases (CO, H, &c.) during solidification. Bar A contained insufficient arsenic to check the solution of gases, and the inference was that the bar contained oxygen. That was confirmed by the authors' tests of the bar after heat treatment in a reducing atmosphere, which, they stated, ruined its mechanical properties. That effect—due to the abstraction of oxygen —was shown by Archbutt,† who passed hydrogen over a solid cylinder of "tough-pitch" arsenical copper at a red heat, thus removing the oxygen and rendering the metal brittle and worthless. Wire made from cathode copper containing no oxygen was unimpaired by the same treatment.

* Platten, J., *Soc. Chem. Ind.*, Mar. 15, 1909.
† *The Analyst*, 1905, vol. xxx. pp. 385 *et seq.*

Those results of the authors were of wide practical significance, and amply confirmed what had already been shown by other workers in the case of arsenical copper, or "tough-pitch" commercial copper free from arsenic, viz. that "gassing" of copper was not only possible, but that it could occur to such an extent as to completely ruin the metal. Similar tests of shorter duration, say half-an-hour or an hour, carried out at a bright red heat, say 900° C., would bring conditions more into line with works' practice, *e.g.* annealing steam-pipes in a coppersmith's furnace, or reheating billets for forging.

But the authors had not only demonstrated the ruinous effects of heating copper in the presence of reducing gases, they had also shown that prolonged heating, at 1000° C. in an oxidising atmosphere, was capable of seriously impairing the qualities of good copper. Test-piece A10, after treatment for three hours at 1000° C., had lost 20 per cent. of its tensile strength and nearly 70 per cent. of its ductility as measured by percentage elongation. Apparently the susceptibility of copper to become overheated lay somewhere between 900° and 1000° C. It would be of use to practical men if that point could be definitely fixed.

The writer thought it highly improbable that lowness in the percentage of arsenic was the direct cause of variable results of mechanical tests.

On p. 52 the authors offered a suggestion regarding the removal of arsenious oxide from molten charges of copper-arsenic alloys which would be quite impracticable even if effective. The effect on the properties of the alloy of tranquil fusion, with entire exclusion of air, would probably be nil. Incidentally the crucible would be deteriorating and fuel wasting. If arsenious oxide did, by reason of its lower specific gravity, rise to the surface of the metal, it would be in a physical condition unsuitable for removal except by the addition of a flux. But the authors were reasoning on a flimsy, if not false, hypothesis. They assumed that if oxygen were contained in the metal it existed as arsenious oxide, whereas both oxygen and arsenic were diffused uniformly throughout the molten metal. When solidification took place, crystals of copper holding arsenic in solution separated out, leaving a eutectic of copper and cuprous oxide to solidify at a slightly lower temperature, forming a network round the crystals of primary solidification. This eutectic might contain arsenic, or rather the copper portion of it most probably did. The facts remained that copper could hold arsenic in solid solution, whilst it could not hold oxygen except in the form of cuprous oxide eutectic, or massive cuprous oxide.

In Plate II., Fig. 8, the photo-micrograph of copper to which arsenious oxide had been added, the dark crystallites and groups of dark specks occupied a greater area than would be occupied if they consisted of As_2O_3. They were more probably crystallites of cuprous oxide and areas of cuprous oxide eutectic. Etching should reveal still more of the smaller specks (eutectic). The conclusion of the authors (p. 51) that cuprous oxide was harmless, so far as the effect of reducing gases was concerned, was quite erroneous, and was based on very meagre and incomplete evidence.

In the experiment with copper containing arsenious oxide there would be considerably more oxygen than in the experiment in which electrolytic copper was melted down with free access of air. Analysis should prove the point, and that would explain why "gassing" should shatter the copper in the former instance, and not apparently affect it in the latter. It was, however, undeniably true that "tough-pitch" electrolytic copper containing oxygen could ·be ruined by removal of that element in the process of "gassing."

Mr. E. F. Law, Assoc.R.S.M. (London), wrote that the paper by Messrs. Bengough and Hill was an excellent example of the intelligent adaptation of scientific principles to the solution of industrial problems, and, as such, the authors and the Institute were to be heartily congratulated upon it.

The destruction of arsenical copper due to the reduction of arsenious oxide by reducing gases, which was very ably shown by the authors, was a point of great interest and importance. Some years ago the writer drew attention to the reduction of oxides in steel which gave rise to blisters, and in the case of hard steels to actual fracture, and the present authors had brought forward another instance of the injurious influence of oxides occurring in metals. Even at the present time the pernicious effect of oxides was not sufficiently realised.

The work on the constitution of the alloys had been admirably conducted, and one of the most interesting points brought out was the way in which the compound Cu_5As_2 preserved its identity (to use the authors' own words) even in solid solution. The somewhat feeble affinity between metals which caused the formation of intermetallic compounds was in many respects similar to that occurring in the formation of double salts, and it was well known that whereas many double salts dissociate in solution, a certain number preserve their identity. It was not unlikely that some of the compounds between metals and the "metalloids" might be analogous to those double salts which did not dissociate on solution.

Mr. Bengough wrote, in reply to the discussion and written communications, that he had carried out a few additional experiments on the effects of reducing gases upon copper containing oxygen and arsenic. In that work he had been without the advantage of the assistance of Mr. B. P. Hill, who had left the laboratory to take up a position under the Great Northern Railway Co. The new work in part confirmed the preliminary work on part of the subject mentioned above, and which was described on pp. 48 to 52 of the paper; there was, however, one important point of difference. Before describing the experiments and offering a summary of the results brought out in the paper, discussion and communications, he wished to remark that one or two members seemed to have mistaken the purpose of the work described on the pages mentioned above, and of the remarks made by the authors thereon. The purpose was to submit certain propositions given on pp. 50 and 51 to the members for discussion. The authors put forward no claim that those propositions had been definitely proved by their work, but stated

definitely that only a few preliminary experiments had been made. The writer quoted from paragraph 3 on p. 52 of the paper, "The authors wish to point out here that the remarks set forth above are merely tentative, and are based on only a few experimental results. They are intended mainly to furnish a discussion which, it is hoped, may prove fruitful in clearing the way for future work." This purpose that section of the paper had served to some extent, and had, therefore, justified itself, although he was now prepared, as a result of further work, to give up entirely one of the propositions named. He turned now to the remarks and communications of individual members.

He would like to thank Professor Huntington for his appreciative remarks on the paper. In regard to his criticism of the statement in the first portion of the paper, that arsenic conferred on copper strength, rigidity, and the power of resisting flames at high temperatures, the authors merely stated what they considered to be the generally accepted opinion on the matter. In a discussion on a paper by Hiorns and Lamb,* Professor Turner, Mr. Hiorns, and Mr. F. Johnson all made statements to that effect, and were not challenged by other speakers. The experiments described in the paper by Mr. Hill and the writer showed that that opinion should be modified, at any rate, to some extent, as stated by Professor Huntington. In regard to the causes of the cracking of the alloys after treatment in reducing gases, further work had shown that cuprous oxide was fully as harmful as arsenious oxide, and that the cause of the negative result described in the paper was the absence of a sufficient amount of the oxide. What was the limiting amount of oxygen, which was permissible without danger of cracking in reducing gases, he was not yet prepared to state, although he was now working on the question. The remarks by Professor Huntington, Dr. Rosenhain, and Professor Carpenter on the causes of the cracking would, perhaps, have been reconsidered by those gentlemen if they had known of those additional experiments, some of which are described below. The authors, therefore, owed those gentlemen some apology. He (the writer) considered, however, that the further work rather lent support to his tentative explanation of the causes of cracking, by the formation of an insoluble gas, since the alternative arsenite theory could not apply to pure copper, copper-oxide systems. In any case further work remained to be done to settle whether or not an arsenite was formed in those alloys, and he was planning a research into the matter.

They were much indebted to Dr. Rosenhain for the expression of his appreciation of the paper, and for his remarks upon it. With regard to the want of homogeneity of the low-arsenic alloys, he was prepared to admit that additional evidence was required before that matter could be definitely accepted. With regard to the striated structure he was much interested in the nickel-steel structure described by Dr. Rosenhain, which was very similar to the one described by the authors in a copper-arsenic alloy. With regard to the slight modification of their interpreta-

* *Journ. Soc. Chem. Ind.*, May 15, 1909.

tion put forward by Dr. Rosenhain, he (the writer) thought they both meant very much the same thing, though, perhaps, Dr. Rosenhain had expressed it better. They owed their thanks to Dr. Rosenhain for pointing out the printer's error on p. 60, which escaped their notice when reading the proofs. He must apologise to Dr. Rosenhain for omitting to mention him as being a member of the International Committee on Copper Specifications.

Mr. E. L. Rhead had contributed several interesting facts to the discussion, for which they were much obliged. With regard to his work on copper containing small amounts of arsenic, they had not found any Cu_3As separating out with so low an arsenic content in the alloy as 0·5 per cent. With 1·3 per cent., and very slow cooling followed by annealing, they had observed it. Perhaps Mr. Rhead's specimens were very slowly cooled or annealed? With regard to his interpretation of Plate II., Fig. 9, they believed the crystal to be due to oxide. It resembled very strongly the cuprous oxide in pure copper, but had a slightly different colour. Its resemblance to an antimony-manganese alloy was interesting, but they did not believe it to be a metallic body; it did not in the least resemble any structures they had found in copper-arsenic alloys made from pure *metals*. He was glad to know that copper-arsenic alloys were specially liable to be attacked by gases containing small quantities of chlorine, as described by Mr. Rhead.

The writer was much obliged to Mr. Archbutt for forwarding to him a very interesting specimen of pure copper, containing oxygen, which had been cracked by heating in hydrogen. He had repeated some of his experiments, and found that cuprous oxide, as he stated, was a cause of cracking. In accordance with Mr. Archbutt's suggestion he (the writer) determined the amount of oxygen contained in bars B, C, and E. The results were as follows :—

	Per Cent.
Bar B (as rolled)	0·20
Bar C (,,)	0·12
Bar E (,,)	0·15

It will be seen that bar B contained rather more oxygen than the other bars. Hence Mr. Archbutt's explanation of the resistance of that bar to reducing gases was insufficient. It seemed probable that the reducing gases failed to penetrate into the bar, and that might, possibly, be connected with the high percentage of arsenic in the alloy. The matter was undergoing further investigation.

The authors wished to tender their best thanks to Professor Carpenter for his appreciative and interesting communication. They were quite in accord with him as to the value of tests carried out at high temperatures, but, as stated on page 37 of the paper, the experimental equipment at their disposal did not permit of such tests. He hoped that that matter would be remedied shortly, and he should then have much pleasure in carrying out the comparative tests suggested by him. With regard to the action of reducing gases, one of the difficulties in the way of their hypothesis, mentioned by Professor Carpenter, had been removed by the

proof of the harmfulness of cuprous oxide. Hence the presence of arsenic was not necessary for the ruin of the alloy.

Mr. F. Johnson sent in a long communication which presented several points of interest. Tests at high temperatures would certainly have been carried out, if they had been possible under the authors' conditions of work. The writer hoped to carry some out later. With regard to the amount of oxygen in the bars, the amounts in bars B, C, and E had been given in the reply to Mr. Archbutt. The other link required by Mr. Johnson might be supplied in part by the following analyses :—

		Per Cent.
Bar C_{15} contains oxygen	. . .	0·10
Bar C_{12} ,, ,,	. . .	0·05

thus showing that the oxygen had been reduced by 50 per cent. by treatment for three hours at 800° C. He was interested to learn Mr. Johnson's opinion on the suggested method of removing arsenious oxide from the alloys. He was, however, not at all prepared to admit his subsequent description of the state of affairs in a crucible of copper containing oxygen to which metallic arsenic was added, nor his view of the changes which took place on solidification. In view of recent work there was little doubt that the oxygen in molten copper would exist as cuprous oxide, and not as uniformly diffused free oxygen. Hence it seemed to him probable that the added arsenic reduced the cuprous oxide, at least in part, and would exist in the copper partly as oxide and partly as metal in solution, as stated in the paper. It was, of course, also possible that the arsenious oxide and cuprous oxide might unite forming an arsenite as had been suggested by several members (and its formation might result in the appearances recorded by Mr. Rhead). In any case the state of affairs was more complicated than that described by Mr. Johnson, and could only be completely elucidated by a thorough study of the triple system, copper-oxygen-arsenic, as was suggested in the paper on page 48. With regard to Mr. Johnson's deduction from the area occupied by the crystallites and specks in Plate II., Fig. 8, he regarded it as quite worthless in view of their irregularity of distribution and the low magnification of the photograph. Mr. Johnson's other remarks had been dealt with elsewhere in his reply to other members.

The authors were indebted to Messrs. Hudson and Law for interesting communications. Mr. Law's analogy between intermetallic compounds and double salts was especially interesting, as was also his reference to the fractures occurring in hard steel, due to the reduction of oxides, to which Mr. Law had drawn attention elsewhere.

THE ASSAY OF INDUSTRIAL GOLD ALLOYS

By ERNEST A. SMITH, Assoc.R.S.M., M.Inst.M.M.

ALTHOUGH a considerable amount of experimental work has been done and much has been written in connection with the assaying of gold bullion generally, the literature of the subject, so far as the text-books and proceedings of societies have been examined, contain comparatively little reference to the assaying of industrial gold alloys, with perhaps the single exception of gold coinage alloys. This is no doubt partly accounted for by the fact that these alloys belong to a more or less special class of bullion, and do not come within the range of work ordinarily dealt with in bullion assay offices.

A comprehensive series of experiments made by A. Riche, Directeur des Essais à la Monnaie de Paris, and recorded in his well-known book "L'Art de l'Essayeur" (Paris, 1888), appears to be the only record of experimental work relating to the assaying of industrial gold alloys.

In the following brief description of the methods in general use for the assay of these alloys the author has embodied the results of experimental work carried out some years ago in the Metallurgical Laboratory of the Royal School of Mines, and more recently in the Metallurgical Department of the University of Sheffield.

For the purposes of this paper the term "industrial alloys" includes the gold alloys of definite composition specially prepared for industrial purposes as distinct from those usually included in the term "bullion," which is conveniently restricted to "the precious metals, refined or unrefined, in bars, ingots, or any other uncoined condition, whether contaminated by admixtures with base metal or not."

The alloys of more or less indefinite composition resulting from the treatment of scrap, lemel, sweep, &c.—obtained during the processes of manufacture—are also included.

It will be observed that many of the experiments detailed in the paper have been made with alloys about 375 standard. This quality of gold was selected as it was thought that the effects of the presence of copper and of silver would be better seen in alloys of low standard than in those of high standard. In the author's opinion an alloy containing less than 37·5 per cent. of gold can hardly be regarded as a gold alloy.

Composition.—The gold alloys most frequently used for industrial purposes are those made to conform to definite standards. As is well known, the standards recognised by law in England are those containing 22, 18, 15, 12, and 9 carats, or parts, of gold in 24 parts, or expressed decimally 916·6, 750, 625, 500, and 375 parts of gold in 1000 parts. In Ireland 20 carat or 833·3 per 1000 is a legal standard, but is seldom used. Alloys of standards, other than the legal standards, are also in use by jewellers for special purposes.

TABLE I.—*Composition of Industrial Gold Alloys of Legal Standard.*

	22 Carat or Standard of 916·6.			18 Carat or Standard of 750.		
Gold . . .	916·8	917·8	917·0	750·6	753·4	752·0
Silver . . .	40·7	7·2	10·3	113·4	126·6	119·4
Copper . . .	42·5	75·0	72·7	136·0	120·0	128·6
	1000·0	1000·0	1000·0	1000·0	1000·0	1000·0
	15 Carat or Standard of 625.			12 Carat or Standard of 500.		
Gold . . .	626·0	631·9	703·5	500·0	500·2	501·0
Silver . . .	107·0	96·6	76·5	165·5	125·3	234·2
Copper . . .	267·0	271·5	220·0	334·5	374·5	264·8
	1000·0	1000·0	1000·0	1000·0	1000·0	1000·0
	9 Carat or Standard of 375.					
Gold . . .	378·0	377·0	378·5	378·3	375·9	376·3
Silver . . .	110·5	200·7	262·5	217·7	104·7	310·7
Copper . . .	511·5	422·3	359·0	404·0	519·4	313·0
	1000·0	1000·0	1000·0	1000·0	1000·0	1000·0

The alloys usually consist of gold-copper, gold-silver, and gold-silver-copper. Alloys of the lower standards frequently

contain zinc, but the proportion is generally small and seldom exceeds 10 per cent. Platinum is also added in some few special cases, but alloys containing this metal are not considered in the paper. The alloys in general use for goldsmiths' work and jewellery vary considerably with regard to the ratio of copper to silver alloyed with the gold. Examples of the actual composition of some of these are given in Table I.*

More examples of 9-carat gold have been given than of any other standard, as this alloy is the one most frequently used, more than 50 per cent. of the gold wares submitted for Hall-marking being of this standard.

It may be pointed out that the gold alloys supplied for the manufacture of wares to be subsequently Hall-marked must obviously assay up to the legal standard, and to ensure this it is the usual practice of the makers of these alloys to add a small quantity of fine gold, usually about 2 grains per ounce of standard alloy, in excess of that required by law. The makers also usually guarantee that the quality of the metal is equal to the standard stated on the invoice, and undertake to make an allowance to the purchaser in the event of the articles made from the metal failing to pass the official test at the Assay Office.

Alloys of Hall-marking quality are sold as such to distinguish them from gold used for the manufacture of articles exempted from Hall-marking, which very frequently assay below the legal standard.

The actual quality of the gold supplied for Hall-marking purposes is shown in Table II., p. 101. The figures represent the mean assay of portions of metal removed from gold wares and transmitted for annual examination to the Royal Mint by the Wardens of the Assay Offices at Birmingham, Chester, and Sheffield, in accordance with the requirements of the Acts of Parliament. No figures for the Goldsmiths' Hall, London, or the Scotch and Irish Halls are published. It will be seen that in all cases the results are above standard and perfectly satisfactory.

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* Further examples of compositions are to be found in Wigley, " Art of the Goldsmith," and Gee, " Goldsmiths' Handbook."

TABLE II.—*Assays of Gold Alloys of Hall-marking Quality.* *

Assay Office.	Year.	9 Carat or Standard of 375.	12 Carat or Standard of 500.	15 Carat or Standard of 625.	18 Carat or Standard of 750.	22 Carat or Standard of 916·6.
Birmingham . .	1903	379·1	507·2	631·8	752·6	917·16
,,	1904	381·1	505·3	632·0	752·4	916·96
,,	1905	379·6	503·6	630·6	753·6	916·96
,,	1906	379·2	507·6	629·2	752·0	917·06
,,	1907	378·4	505·2	628·4	751·1	917·36
Chester . . .	1903	382·7	504·6	630·8	752·7	917·06
,,	1904	383·7	500·0	629·1	753·0	917·06
,,	1905	381·1	511·9	629·3	753·1	916·86
,,	1906	383·0	504·4	629·0	752·6	917·26
,,	1907	380·8	517·2	628 7	752·6	917·66
Sheffield . .	1903	No gold diet submitted for assay until 1904				
,,	1904	382·1	None sent	627·5	754·0	916·86
,,	1905	383·4	572·0	628·3	754·8	917·46
,,	1906	390·2	506·8	627·8	751·3	919·06
,,	1907	381·5	503·8	628·1	752·0	923·66

Sampling.—The method of sampling gold alloys varies according to their condition. When in the form of ingots, slabs, or bars they are sampled in the ordinary way by cutting a single sample from a corner or the middle of one side. Experience proves that in the case of alloys of high standard these samples are usually representative of the whole mass. In dealing, however, with bars of low standard alloys, it is very advisable to take two samples by cutting diagonally opposite corners from the upper and lower sides, as alloys containing a large proportion of copper are always subject to more or less segregation during solidification, even when every precaution has been taken in melting, and they are consequently not perfectly uniform in composition. The researches of Peligot, Roberts-Austen, Rose, and others have shown that practically no segregation occurs in the gold-silver and gold-copper alloys rich in gold and free from all impurities; but in the case of many of the ordinary trade bars of gold alloys, more especially those of low standard, the discrepancies frequently met with between the assays of samples taken from different parts of the bars prove that they are seldom

* From the Annual Reports of the Royal Mint.

uniform in composition, although in many cases the differences in the assay results are comparatively small.

The errors due to the non-homogeneous character of the alloys are, of course, to some extent modified by rolling the bars. Still the general experience is that assays of samples from the centre of fillets especially of low standard alloys invariably differ slightly from samples taken at the edges. These differences in the gold-content may be considerable when proper care has not been exercised in the preparation of the alloy. The question of segregation in ternary alloys of gold–silver-copper is of considerable interest and importance, and one upon which more experimental work remains to be done.

The bars resulting from the treatment of scrap and lemel vary considerably in fineness, and are very seldom uniform in composition owing to the presence of impurities, and also in some cases to want of care in melting. To ensure getting a representative sample the bar should be remelted and well stirred before casting : the resulting ingot should be sampled by drilling in at least two or three different places.

When the alloys are in the form of sheet or wire, or of manufactured articles, considerable care has to be exercised in sampling, as the surface is invariably richer in gold than the interior owing to the "pickling" or "blanching" to which the metal is subjected to remove the coating of oxide formed during the operations of annealing, soldering, &c. The removal of this enriched or "coloured" surface before sampling is very necessary, as it is obvious that if it is included in the sample the result obtained for the gold assay will be too high and will not represent the true fineness of the alloy.

In the case of sheet metal and wire, which are readily sampled by cutting off a piece with the shears or pliers, the errors introduced in the gold assay, when the coloured surface is included in the sample, are largely dependent on the thickness of the sheet * or wire and the standard of the alloy. As a general rule the errors are smaller

* The minimum thickness allowed by the Assay Offices for gold wares is 0·0076 inch No. 36 Imperial Standard Wire Gauge).

with the alloys of higher standard, as there is less base metal to be dissolved out. Assays made by the author show that the errors on sheet metal may vary from 0·5 to 2 or 3 parts per 1000 or more above the correct standard of the alloy.

In the case of gold wares where it is usually necessary to scrape the surface in order to obtain a sample, the removal of the "colour" becomes a matter of extreme importance: if it is not removed before sampling the errors on the gold assay will be much greater than those given above for cutting samples of sheet metal, but the extent of the errors will necessarily be dependent on the depth to which the scraping is carried, and also the area covered in taking the sample. In sampling gold-plate and articles of jewellery the assayer is confronted with difficulties which do not arise in connection with the sampling of sheet metal and gold bullion, as the area from which a sample can be taken in the former cases is frequently very limited. The errors arising from the inclusion of the coloured surface in the case of scraping samples may vary from a few parts per 1000 to anything up to 100 parts per 1000, or even more in exceptional cases.

At the Assay Offices for Hall-marking it is the usual practice to remove the "colour" from gold wares by a preliminary scraping, or by "buffing" before scraping to obtain the sample proper.

Methods of Assaying.—The methods employed for the assay of gold alloys are similar in principle to those universally adopted for the assay of ordinary gold bullion, and involve cupellation to remove the oxidisable metals and inquartation with subsequent parting in nitric acid to separate the gold.

The proportion of copper, however, in industrial gold alloys is greater than in ordinary gold bullion, as already shown by the analyses in Table I., p. 99, and on this account more lead has to be employed for cupellation. The amount of lead required is dependent on the following facts. Copper has a greater affinity for gold than for silver, and it is necessary to use a larger proportion of lead to ensure its oxidation when com-

bined with gold than when in combination with silver.   This proportion varies according to the composition of the alloy and the temperature used for cupellation, but experience has shown that for any given standard the amount of lead necessary for gold-copper alloys is about twice that required for silver-copper alloys of the same standard.

As the result of repeated experiment it has been found that the maximum quantity of lead required to eliminate copper in the case of gold-copper alloys is about 32 times the weight of alloy taken, while for silver-copper alloys about 16 times will suffice.   It must, however, be pointed out that although the greater part of the copper present in a gold-copper alloy will be eliminated during cupellation by the addition of a suitable quantity of lead, the resulting gold button in all cases obstinately retains a small quantity of copper which cannot be entirely eliminated even by a second cupellation with a fresh quantity of lead.

The separation of copper from gold is greatly facilitated by the presence of silver, and as this metal is usually present in industrial alloys or is added for parting purposes, it has to be taken into account when making up the cupellation charge.

From these remarks it will be evident that the quantity of cupellation lead has to be carefully regulated according to the amount of copper and of silver alloyed with the gold.   If insufficient lead is used the copper will not be completely removed, and if too much lead is employed the cupellation losses will be excessive.

It is the co-existence of the above facts that make it somewhat difficult to decide upon the best quantity of lead to use, especially when the approximate composition of the alloy is unknown, and it is not surprising to find a want of agreement on this point amongst different authorities, as the following tables show.

For alloys in which the alloying metal is copper only, the proportions recommended by D'Arcet, Kandelhardt, and Cumenge and Fuchs respectively are as follows :*—

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* Quoted from " Metallurgy of Gold," T. K. Rose.

TABLE III.—*Proportions of Lead for Cupellation of Gold-Copper Alloys.*

Gold in 1000 Parts.	Amount of Lead Employed for One Part of Alloy.		
	D'Arcet.*	Cumenge and Fuchs.†	Kandelhardt.‡
1000	1	1	8
900	10	14	16
800	16	20	20
700	22	24	24
600	24	28	24
500	26	32–34	28
400	34	32–34	28
300	34	32–34	32
200	34	32–34	32
100	34	30	32
50	34	28	32
0	...	11	32

Kandelhardt's table is modified to make it uniform with the others.

As Dr. Rose has remarked, " It is difficult to understand the small quantity of lead assigned by Cumenge and Fuchs to the alloys containing less than 200 parts of gold per 1000."

From the compositions given in Table I., it will be seen that the majority of the industrial gold alloys are ternary alloys of gold-silver-copper, and for the cupellation of these less lead is required than the quantities just given.

As the result of experiments on the cupellation of industrial gold alloys of different compositions, Riche suggested that the most suitable proportions of lead would be the mean of the quantities recommended by D'Arcet for the cupellation of gold-copper and of silver-copper alloys respectively. The quantities obtained in this way are given in Table IV., which is compiled from D'Arcet's well-known tables.

These quantities recommended by Riche agree fairly closely with those now in general use, as will be seen from the following table, which gives the quantities of lead for the cupellation of gold alloys of the legal standards recommended

* Pelouze and Frémy, *Traité de Chimie Générale.*
† *Encyclopædie Chimique*, vol. iii., L'Or, p. 154.
‡ *Gold-Probirverfahren*, Berlin, p. 3.

TABLE IV.—*Quantities of Lead for Cupellation of Gold-Silver-Copper Alloys.*   (*Suggested by Riche.*)

Standard. Gold or Silver in 1000 Parts.	Lead Employed for One Part of Alloy. (D'Arcet.)		
	Gold-Copper Alloys.	Silver-Copper Alloys.	Mean Quantities for Gold-Silver-Copper Alloys.
1000	1	0·3	0·65
950	...	3	3
900	10	7	8·5
800	16	10	13
700	22	12	17
600	24	14	19
500	26	16–17	21·5
400	34	16–17	25·5
300	34	16–17	25·5
200	34	16–17	25·5
100	34	16–17	25·5

by different assayers experienced in assaying these alloys. The table is compiled from notes kindly communicated to the author at various times.   Riche's table is inserted for comparison, and is modified to make it uniform with the others.

TABLE V.—*Quantities of Lead used by different Assayers for the Cupellation of Legal Standard Gold Alloys.*

Standard.			Amount of Lead Employed for One Part of Alloy.						
Gold in Parts per 1000.	Carats.	Riche.	Assayer A.	Assayer B.	Assayer C.	Assayer D.	Assayer E.	Assayer F.	Assayer G.
916·6	22	8	8·3	14·4	13·0	12	8	6	16
750·0	18	15	16·6	14·4	15·6	16	15	8	16
625·0	15	18	16·6	16·8	22·4	22	18	22	24
500·0	12	21	16·6	16·8	22·4	22	20	28	30
375·0	9	25	25·0	16·8	24·0	24	24	38	30

The author prefers the quantities given in column E, which are very similar to those recommended by Riche.

As an interesting exception to the above quantities, it may

be mentioned that Mr. W. F. Lowe, of the Chester Assay Office, uses the same weight of lead for alloys of all standards, viz. about twenty times the weight of the sample taken.

The method of adding the lead varies with individual assayers, but when using the larger quantities necessary for low standard alloys, it is not usual to add all the lead in one charge. The general practice appears to be to wrap up the assay piece and the necessary parting silver in a piece of lead foil of convenient size, and to "ball up" separately the remainder of the lead required.

In charging the assays into the furnace, the lead containing the assay piece is charged either before or after the ball of extra lead and as soon as the first lot has melted.

When a furnace load consists of assays of alloys of varying standards, the charging in of the different quantities of lead should be so arranged that all the cupellations will finish at the same time.

It is with this object in view that Mr. Lowe uses the same weight of lead for all standards.

It may be pointed out here that it is the practice of some assayers to employ less lead than the quantities given in the above Table V., with the object of obtaining well-formed, clean and bright buttons suitable for parting. In this case the assay piece and parting silver are wrapped in two-thirds of the total lead and charged in first, and, after the cupellation is finished, the remainder is added in the form of a bullet. This practice is adopted for the three lower standards by the assayer B, hence the smaller quantities of lead given in the table for these alloys.

The practice was also adopted by Mr. F. W. Bayly, A.R.S.M., for many years senior assayer of the Royal Mint, and the proportions of lead employed by him for various gold-copper alloys may be quoted as another example.*

The figures given in the table for the five legal standards have been calculated by the author from Mr. F. W. Bayly's quantities, and are inserted for comparison.

The absorption of gold by the cupel is greater by this method, but it is not excessive when precautions are taken

* Rose, "Metallurgy of Gold," 2nd ed., p. 435.

TABLE VI.—*Quantities of Lead for Cupellation of Gold Alloys when added in Two Separate Charges.   (F. W. Bayly.)*

Standard.	Amount of Lead used for One Part of Alloy.		
	Lead for First Charge, Two-thirds.	Lead for Second Charge, One-third.	Total Lead.
916·6	8·0	...	8·0
770·0	9·84	4·91	14·75
750·0	10·0	5·0	15·0
666·0	10·70	5·30	16·0
625·0	11·0	5·50	16·50
546·0	11·66	5·84	17·50
500·0	11·66	5·84	17·50
375·0	12·0	6·0	18·0
333·0	12·0	6·0	18·0

to avoid too hot a fire : the buttons are always bright, well formed, and clean.

The exact method of procedure adopted in assaying industrial gold alloys varies according to requirements. For many commercial purposes an exact determination of the percentage of gold is all that is required; in other cases the percentage of silver is also required, or the complete composition of the alloy may be desired.

Assay for Gold only.—For the determination of gold only from 0·25 to 0·50 gramme (500 to 1000 millièmes gold assay weights) of the alloy is weighed, and cupelled with the addition of silver equal to two and a half times the weight of the gold assumed to be present, and sufficient lead to remove the copper.

The resulting gold-silver button is flattened and parted, and the gold cornet weighed in the ordinary way.

This method, as previously stated, is the one universally adopted for the assay of gold bullion. A detailed description is therefore unnecessary here, but the following remarks may be made.

For the cupellation the quantities of lead given in Table V. are used.

As is well known, certain losses and gains (the sum of which is called the surcharge) take place during the cupel-

lation and parting of gold alloys, the losses being due to (1) absorption by the cupel, (2) volatilisation, and (3) solution in the acid, and the gains to the retention of silver by the gold cornet.   The amount of the surcharge varies with the conditions of working and the composition of the alloy, the general experience being that the losses under all three heads are greater as the percentage of copper in the alloy increases.

With regard to the losses in cupellation, it has been proved experimentally that the gold lost by volatilisation is inconsiderable compared with the absorption by the cupel, although it would appear that the loss by volatilisation, though small, is proportionally greater with an increase in the temperature of cupellation.

Much of the experimental work done in connection with the loss of gold in cupellation relates to gold alloyed with either silver or copper, and the results are not therefore altogether applicable to ternary alloys of gold, silver, copper, of which most of the industrial alloys consist.

Rossler * has shown that " the loss of gold in cupellation increases with the amount of lead used, and decreases as the amount of silver is increased," facts which are quite in accordance with the result of more recent experiments and with general experience.   The loss of gold in cupellation is also considerably influenced by the presence of copper, experience showing that an increase in the percentage of copper results in an increase in the loss of gold.   According to Rose, the " loss of gold is about 0·3 or 0·4 per 1000 when the copper in the gold does not exceed 10 per cent., and more if larger quantities of copper are present."   The loss on the cupel is also dependent on the quantity of gold in the assay piece.   In ordinary assays of gold alloys it is usual to take a constant weight of the alloy for all standards ; hence, as pointed out by Beringer,† it will be obvious that as the weight of copper in the cupel charge increases, the weight of gold decreases.   The silver, on the other hand, is always approximately two and a half times as much as the gold, whatever its quantity may be.

But the cupellation loss, as previously pointed out, is

* *Dingler's Polytechniches Journal*, vol. 206, p. 185.
† "A Text-book of Assaying."

smaller with less gold and greater with more copper, and it so happens in assaying these alloys that under suitable conditions these two opposites may nearly neutralise one another.

In this connection some interesting results have been obtained by Mr. W. F. Lowe * of the Chester Assay Office.

He found that the gold recoverable from the cupels on which 20 grains of gold alloys had been assayed was almost identical, although the standards of the alloys varied from 916·6 to 375·0. The results are given in the following table :—

TABLE VII.—*Gold absorbed by Cupel during Cupellation of Gold Alloys.* (*W. F. Lowe.*)

Standard.	Actual Weight of Gold in 20 Grains of Alloy Cupelled.	Loss of Gold per 1000 of Actual Gold Present.	Weight of Gold obtained from 1 Cupel (=4 Assays of 5 Grains each).	Absorption in Parts per 1000.
	Grains.		Grains.	
916·6	18·3	0·765	0·014	0·70
750·0	15·0	0·966	{ 0·014 \ 0·015	0·70 \ 0·75
625·0	12·5	1·160	{ 0·014 \ 0·015	0·70 \ 0·75
375·0	7·5	1·866	{ 0·014 \ 0·014	0·70 \ 0·70

Mr. Lowe remarks "that the above were all cupelled on different days, so that the temperature of the furnace would not account for this regularity; but as the amount of lead used is the same (about 20 times the weight of the sample taken) for all standards, this, most probably, is the cause of the regularity." The heavier losses shown in the third column, added by the author, are mainly due to the increase in the proportion of copper in the separate alloys.

By altering the weight of lead, or in any other manner modifying the working conditions, other figures would of course be obtained.

* " Assaying and Hall-marking at the Chester Assay Office," W. F. Lowe, A. R.S.M., *Journal of the Society of Chemical Industry*, 1889, vol. viii. p. 687.

In practice it is more usual, as already explained, to vary the lead with the varying fineness of the samples, and under these conditions the general experience appears to be that the loss due to absorption into the cupel is "greater with alloys of low standard than with those of high standard."

In addition to the cupel losses there is the loss of gold by solution in acid during parting, but experience proves that this loss is comparatively small.

The total losses may or may not be counterbalanced by the silver retained by the gold after parting, which amounts to about one part per thousand under normal conditions of working. In practice it is found that with alloys rich in gold the silver retained by the cornet more than compensates for the various losses and the surcharge is positive; but with alloys of low standard the losses are greater and the surcharge is negative, the cupellation loss being usually greater on account of the larger proportion of copper present, as previously pointed out.

TABLE VIII.—*Surcharge on Assays of Gold Alloys obtained by Different Assayers.*

Standard.	Pelouze and Frémy.*	Rose.†	Lowe.‡	Smith. §
916·6	...	+0·250	+0·06 to +0·07	+0·1 to +0·35
900·0	+0·25	+0·225	...	...
800·0	+0·50	−0·075	...	...
750·0	...	...	0·00	0·0 to +0·25
700·0	0·00	...	...	...
666·6	...	−0·200	...	...
625·0	...	...	0·00	0·0 to +0·2
600·0	0·00	...	...	...
546·0	...	−0·700	...	...
500·0	−0·50	...	0·00	−0·1 to −0·5
400·0	−0·50	...	...	...
375·0	...	...	−0·06 to −0·07	−0·2 to −0·6
333·3	...	−2·800	...	...
300·0	−0·50	...	...	...
200·0	−0·50	...	...	...
100·0	−0·50	...	...	...

* "Experiments on Synthetic Alloys of Gold and Copper," *Traite de Chimie*, 3rd ed., vol. iii. p. 1230.

† Compiled from results obtained at Royal Mint, "Metallurgy of Gold."

‡ Results obtained at Chester Assay Office, *Journal of the Society of Chemical Industry*, 1889, vol. viii. p. 687.

§ Compiled from a number of results obtained by the author.

Examples of the surcharge obtained in the assay of gold alloys of various standards by different assayers are given in Table VIII. The figures represent only the relative surcharges; the absolute amounts vary with the treatment, but when a very systematic and uniform method of working is adopted the variations are very slight.

The necessity of using checks and of working all assays under exactly the same conditions in all cases where results of extreme accuracy are desired, is well known to all bullion assayers, and cannot be too strongly emphasised in dealing with the assay of gold alloys.

To make the assays absolutely comparable, it is essential, especially when the alloys contain much copper, that the composition of the check should approximately correspond to the composition of the alloy being assayed. When the approximate composition of an alloy is not known, a preliminary assay must be made to determine this, as described subsequently.

It will be seen, however, from Table I., given on p. 99, that there is considerable variation in the composition of the alloys of low standard, and when a large number of different alloys of any particular standard have to be assayed, it would be exceedingly laborious to have to make up checks to correspond in composition to each alloy. It is the usual practice, therefore, in such cases to make up the checks to conform to an alloy of average composition.

When assaying gold alloys of the legal standards, the author uses checks which correspond in composition to the representative alloys given in Table IX., p. 113, pure metals being used for the purpose.

In each case silver is added to make the total weight of silver equal to two and a half times that of the gold.

In practice it is usual to disregard any silver that may be present in the alloy being assayed, and to add the same total weight of silver to both checks and samples, unless a preliminary examination indicates the presence of more than an average amount of silver. When great exactness is not required it is sometimes convenient to use for check purposes a piece of alloy the exact composition of which has been determined and of the same standard as

TABLE IX.—*Composition of Representative Gold Alloys
used for Checks.*

	9 Carat or Standard of 375.	12 Carat or Standard of 500.	15 Carat or Standard of 625.	18 Carat or Standard of 750.	22 Carat or Standard of 916·6.
Gold	375·0	500·0	625·0	750·0	916·6
Silver	156·5	166·0	94·0	125·0	41·4
Copper	468·5	334·0	281·0	125·0	42·0
	1000·0	1000·0	1000·0	1000·0	1000·0
Ratio between copper and silver .	Cu 3 Ag 1	Cu 2 Ag 1	Cu 3 Ag 1	Cu 1 Ag 1	Cu 1 Ag 1

the alloy to be assayed. Dr. Rose [*] has drawn attention to the advantages to be gained by using a gold-silver alloy instead of weighing separate quantities of pure gold and pure silver in preparing checks.

Assay for Silver.—Silver in gold alloys is usually determined by difference, the gold and silver being weighed together after cupellation, and the gold determined separately in the same or another portion of alloy.

When one assay piece only is used for the determination of both gold and silver, from 0·2 to 0·5 gramme of the alloy is cupelled with enough lead to remove all the copper, but without the addition of silver for parting purposes. In this respect it differs from the method just described, in which the copper is eliminated and the silver at the same time incorporated with the gold by a single cupellation with lead.

The gold-silver button resulting from the cupellation is carefully weighed and then subjected to inquartation and parting in the ordinary way. By subtracting the weight of the gold-cornet from the weight of the gold-silver button the proportion of silver is at once ascertained.

To obtain reliable results by this method considerable practice is required, and special attention must be given to the proportion of lead employed and to the temperature of

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[*] Thirty-second Report of Royal Mint, 1901, p. 73.

cupellation. These must necessarily to a large extent be left to the judgment and experience of the assayer, based on a preliminary examination of the alloy.

The quantities of lead given in Table V. are representative of those in general use for the cupellation designed for the removal of the copper, but some assayers prefer to use the quantities given for gold-copper alloys in Table IV. or even larger quantities. Experience has shown, however, that the copper can be more completely separated from gold alloys and less silver lost by cupelling at a higher temperature with a small quantity of lead than by employing more lead and working at a lower temperature. As the loss during cupellation is largely dependent on the amount of gold and copper present, the temperature must be varied in accordance with the composition of the alloy in order that the loss may be minimised as much as possible.

In cases where the gold predominates, the finish of the cupellation should be effected at a higher temperature than in the case where the quantity of gold is small. For alloys of low standard the temperature at the beginning should be very little above that ordinarily employed for silver assays, and should be increased gradually until at the end it approaches more to that employed for the cupellation of gold. Assayers who use the larger quantities of lead invariably cupel at the lowest possible temperature. Gas muffles are undoubtedly the best form of furnace to use for these assays, as the temperature is far more readily controlled in these than in coke-fired furnaces.

The effect of varying quantities of lead in cupellation has been ascertained by Riche in the series of experiments already referred to. Table X., p. 115, gives the results of his experiments on 0·5 gramme synthetic alloys of gold-silver-copper cupelled in the quantities of lead recommended by D'Arcet for gold-copper and gold-silver alloys respectively (see Table IV., p. 106). The results have been tabulated by the author for convenience of reference.

The author has repeated many of Riche's experiments, and confirmed his conclusions that the surcharge resulting from the cupellation may vary considerably according to the amount

TABLE X.—*Surcharge on Cupellation of Gold-Silver-Copper Alloys with varying Lead.* (*Riche.*)

Composition in Parts per 1000.			Amount of Lead used for 1 Part of Alloy.	Surcharge. Parts per 1000.	Amount of Lead used for 1 Part of Alloy.	Surcharge. Parts per 1000.
Gold.	Silver.	Copper.				
900	50	50	10	} +5·0 to +8·0	7	} +12·0 to +15·0
900	25	75	10		7	
800	150	50	16	No surcharge	10	} +8·0 to +10·0
800	100	100	16	} Slight	10	
800	50	150	16	surcharge	10	
700	200	100	22	} Very slight surcharge	12	} +5·0 to 8·0
700	100	200	22		12	
700	50	250	22		12	
600	300	100	24	} −2·0 to −5·0	14	No surcharge
600	200	200	24		14	} +4·0 to +9·0
600	100	300	24		14	
600	50	350	24		14	
500	400	100	26	} −3·0 to −10·0	16–17	} Assays approach exactness perhaps a little high.
500	300	200	26		16–17	
500	200	300	26		16–17	
500	100	400	26		16–17	
500	50	450	26		16–17	
400	...	...	34	...	16–17	Exact.
300 and less	...	...	34	Exceeds −10·0	16–17	Exceeds −10·0

of lead employed and the temperature of cupellation. The influence of the temperature of the furnace on the cupellation losses is shown by the results (Table XI.) obtained by the author on synthetic alloys cupelled with varying quantities of lead and at different temperatures. The alloys were 375 standard, and the ratio of copper to silver varied from 2 to 4 parts of copper to 1 part of silver.

The method previously mentioned of using less lead for the cupellation and of adding it in two separate quantities (viz. adding one-third after the other two-thirds have worked off) may also be adopted with advantage for direct cupellation without parting silver.

The resulting gold-silver buttons are always much brighter and more satisfactory, and, provided the quantity of lead and

TABLE XI.—*Surcharge on Gold Alloys Cupelled direct with Varying Lead and at Different Temperatures.*

Lead to One Part of Alloy.	Surcharge in Parts per 1000.		
	Low Temperature.	Medium Temperature.	High Temperature.
35	− 5·6	− 6·8	− 8·0
35	...	− 7·7	− 17·0
30	+ 1·0	− 5·7	...
30	+ 1·3	− 3·0	...
30	...	− 3·7	...
30	...	− 2·3	...
25	+ 2·0	− 3·8	− 8·4
25	0·0	− 4·0	− 11·0
25	+ 3·5	− 6·3	− 17·8
25	+ 3·3	− 6·7	− 14·6
25	− 1·3	− 5·2	− 15·0
25	− 2·0	− 7·7	− 16·7
25	+ 0·8	− 7·3	− 21·0
20	+ 2·0	+ 1·3	− 7·7
20	...	...	− 6·7
20	...	...	− 7·0
18	+ 8·7	+ 4·1	− 3·0
15	+ 13·7	+ 2·8	− 5·0

the cupellation temperature are carefully regulated, the loss of gold and silver on the cupel, although generally greater than when the lead is added in one charge, is not excessive. Some results obtained by the author with synthetic alloys, by both methods, are given in Table XII., p. 117.

It would appear from tests made by the author that when a suitable quantity of lead is employed the copper is more satisfactorily eliminated with two successive charges than with one charge.

With a little experience the best quantity of lead for two charges for any particular alloy is readily ascertained, and undue cupellation loss avoided. The temperature of cupellation should be kept low until the first charge has worked off, and then raised during the working off of the second charge.

TABLE XII.—*Comparison of Cupellation Surcharge on Gold Alloys when the Lead is added* (1) *in one charge ;* (2) *in two charges.*

No.	Standard of Alloy.	Lead in One Charge.		Lead in Two Charges.	
		Lead to 1 Part of Alloy.	Surcharge. Parts per 1000.	Lead to 1 Part of Alloy.	Surcharge. Parts per 1000.
1	375·0	35	−4·8	25·0	−5·4
2	375·0	30	−6·0	20·0	−5·0
3	375·0	25	−5·8	15·0	−3·0
4	375·0	32	−7·5	18·0	−4·0
5	375·0	35	0·0	25·0	−4·5
6	376·0	24	−4·0	24·0	−11·0
7	375·0	30	−2·7	20·0	−6·0
8	375·0	30	−1·7	20·0	−6·0
9	375·0	24	−4·0	24·0	−11·6
10	500·0	30	+3·0	20·0	−2·5
11	500·0	28	+5·0	17·5	+2·5
12	500·0	28	−4·0	17·5	−8·0
13	628·7	20	+4·3	20·0	−8·6
14	625·0	24	−1·0	16·5	−3·0
15	625·0	25	+4·0	18·0	0·0
16	750·0	22	+6·0	15·0	+5·0
17	750·0	22	+4·0	15·0	+2·5
18	750·0	22	−0·5	15·0	−3·0
19	750·0	22	−0·7	25·0	−5·5
20	752·0	22	+5·0	15·0	+7·0

In order to ascertain the percentage of silver in the alloy it is necessary, as already pointed out, to determine the gold, and, if this has not been done in a separate assay piece, the gold-silver button from the cupellation is carefully weighed, inquarted with silver, and parted.

The amount of silver to be added for inquartation can be ascertained from the preliminary assay, or by the touchstone, but an experienced assayer can frequently judge the quantity required with sufficient accuracy from the colour of the gold-silver button.

Buttons containing from 20 to 40 per cent. of silver have a greenish-yellow tint, but, when the silver amounts to 50 per cent., the yellow tint is scarcely perceptible. With more than 50 per cent. of silver the buttons are silver-white.

The inquartation is best effected by cupellation with the smallest convenient quantity of lead. The practice of alloying the silver by means of the blowpipe is to be deprecated.

The results obtained for gold by this indirect method are approximately accurate when due care is exercised, but they are invariably lower than those obtained for the gold determined in a separate assay piece by direct cupellation with parting silver.

The difference is, no doubt, partly accounted for by the fact that, in the latter case, the presence of the parting silver facilitates the elimination of the copper, and also helps to reduce the loss of gold.

The actual differences between the two methods obtained with gold alloys of varying standards is given in the following table, compiled from results obtained by the author :—

TABLE XIII.—*Comparison of Results for Gold determined by* (1) *Single Cupellation, with Parting Silver direct ; and by* (2) *Double Cupellation.*

Approximate Standard of Alloys.	Single Cupellation. Gold Direct.	Double Cupellation. Gold Indirect.	Difference. Parts per 1000.
375·0	381·9	380·0	−1·9
	374·0	372·0	−2·0
	376·0	374·4	−1·6
	376·4	375·9	−0·5
	375·0	372·5	−2·5
	377·1	376·3	−0·8
500·0	467·1	467·0	−0·1
	537·0	536·2	−0·8
	499·3	497·7	−1·6
	499·8	497·7	−2·1
625·0	628·5	627·0	−1·5
	625·7	623·3	−2·4
750·0	752·6	751·0	−1·6
	750·3	749·4	−0·9
916·6	918·0	917·3	−0·7
	917·1	916·7	−0·4

From the experiments tabulated above, it will be evident that, in the hands of an inexperienced assayer, the results obtained for the determination of the gold and silver by the double cupellation method may be far from accurate, and, since the losses and gains previously detailed are dependent on so many conditions, it is always necessary, in all cases where extreme accuracy is desired, to use checks. This method of double cupellation, or " Parting Assay," in which the gold and silver are determined in the same assay piece, is largely used by trade

assayers for the valuation of lemel bars, &c., and, in the hands
of experienced assayers who have ascertained the best working
conditions for the particular class of alloys with which they
have to deal, the results are sufficiently accurate for commercial
purposes.

It is not the usual practice of trade assayers to use checks
except in special cases, but it may be remarked that the
increasing demand for greater accuracy in trade assays is
causing checks to be more frequently used than was formerly
the case. A check, consisting of a piece of plate of known
composition and of similar standard to the alloy being assayed,
will meet the requirements in most cases. The results re-
corded above show to what extent the method is reliable when
checks are not used.

In making assays by this method, it is well to remember
that it is the weight of the gold which is the most important,
because of its value, and the working conditions should be such
that no undue loss of gold is occasioned.

As uniformity of temperature is very necessary with this
method, a few assays only should be cupelled at the same
time in order to avoid extreme variations of temperature, and
the batch of cupels should be surrounded by empty cupels.

When the exact determination of the gold and silver in an
alloy is required, the author prefers to determine the gold by
direct cupellation with parting silver, and to determine the
silver in a separate assay piece by direct cupellation with lead
only, checks being used in both cases.

Another method employed for the determination of silver
in gold alloys, consists in cupelling the alloy with lead and
parting silver as already described, and then deducting the
weight of the parting silver from the weight of the gold-silver
button resulting from the cupellation.

In this case the parting silver must be accurately weighed,
but, unless checks are worked off at the same time as the
alloys, the results are of little value, except, perhaps, as a guide
to the approximate composition of the alloy.

If checks are not used the whole of the cupellation loss
will be thrown on to the silver in the alloy. This will be
evident from the following figures, which give the results of

an assay on a 0·5 gramme sample of gold bar from clean lemel :—

	Gramme.	
Weight of gold and silver button from cupellation .	0·7660	
Less parting silver	0·4750	
Gold and silver in alloy	0·2910	
Gold after parting	0·1896	=379·2 per 1000
Difference=Silver in alloy	0·1014	=202·8 per 1000

The total cupellation loss on a check worked off at the same time was ·0065, and, if this figure is added to the above result, it will make the silver in the alloy 0·1079 or 215·8 parts per 1000, instead of 0·1014 or 202·8 parts per 1000, a difference of 13 parts per 1000.

Experiments conducted by the author, with standard alloys, show the average total cupellation loss when 1000 millièmes (0·5 gramme) of alloy are cupelled with parting silver direct to be as follows :—

TABLE XIV.—*Relative Cupellation Losses on Gold Alloys Cupelled direct, with the addition of Parting Silver.*

Standard of Alloy.	Average Loss on 1000 Millièmes + Parting Silver.
916·6	26·1
750·0	23·0
625·0	22·5
500·0	20·3
375·0	19·5

These figures represent the relative losses only; the actual losses will vary with the composition of the alloys, the proportion of lead and temperature of cupellation.

Assay to determine Composition of Alloy.—When the complete composition of an alloy is desired, the gold and silver are determined by the methods described, and the copper estimated by difference. The following is an example.

An ingot resulting from the melting of scrap gave :—

	Parts per 1000.		Composition.	
Gold and silver . .	683·8	Gold . . .	503·7
Gold	503·7	Silver . . .	180·1
		Copper . . .	316·2
Difference=Silver . .	180·1		1000·0

1000 − 683·8 = 316·2 Copper.

If zinc enters into the composition of an alloy it will be detected on the cupel as a scoria during the first stages of the cupellation. When it is required to know the amount present the alloy must be treated with aqua regia and the zinc estimated by any of the well-known methods.

Preliminary Assay.—When the composition of an alloy is quite unknown, a preliminary assay must be made to approximately ascertain this in order to determine the correct quantities of silver and lead to be added.

It very frequently happens, however, that the standard of the alloy is stated when the sample is sent for assay, and even when this is not the case a knowledge of the source of the metal will often be a sufficient guide for adjusting the lead, &c.

An experienced assayer will frequently be able to decide the approximate composition from the hardness and appearance of the metal and the effect of the action of nitric acid or other "test" acid. The colour alone is not a sufficient indication of the standard, as alloys of low standard are made to resemble alloys of higher standard by the careful regulation of the proportion of silver and of copper. The "test" acid used by the author is that recommended by Wigley,* and consists of nitric acid, 4 oz.; hydrochloric acid, 0·5 oz.; and water, 3 oz.

After considerable experience it is possible to determine, with a fair degree of accuracy, the standard of any given alloy, but it may be remarked that the action of the acid is not quite the same in every case with alloys of the same standard but of different composition. For example, an alloy 375 standard containing a large percentage of copper is more readily acted upon than an alloy of the same standard in which the alloying metal is mainly silver. If these tests are not sufficient to indicate the quality of the gold, this may be determined by the touchstone or by cupellation. In the latter case about 0·25 gramme of the alloy is cupelled with from 15 to 30 times its weight of lead, and the resulting gold-silver button weighed and then inquarted with silver and parted. Should the cupellation button

* Wigley, "Art of Goldsmith and Jeweller."

be unsatisfactory it must be returned to the muffle and more lead added.

It is the practice of some assayers to make the preliminary assay serve the purpose of an assay for the determination of the silver, the results being regarded as sufficiently near for many purposes, and to make a separate assay for gold based on the information obtained.

Reporting.—The results of assays of gold alloys are reported either decimally in the ordinary way or by the " carat " system, according to requirements. The former method is now being more generally adopted, but the older " carat " system is still used, as the generality of workers and dealers in gold and silver alloys are more conversant with this system of computation than with the decimal equivalent; it is, therefore, the usual practice of trade assayers in reporting the proportion of gold in jewellery alloys to refer always to the legal gold standard of 22 carat (916·6). These reports are readily understood when it is remembered that " standard gold " (916·6) contains in 24 parts, 22 of gold and 2 of other metal; these parts, as is well known, are called carats, the gold carat containing 4 grains and the grain being subdivided into 8 parts. In reporting how much gold in carats, grains, and eights is present in an alloy above or below the legal " standard," the conventional terms " betterness " and " worseness " are used, the metal being reported as B^r (abbreviation for better) or as W^o (abbreviation for worse).

For example, a sample of 18-carat gold would be reported as 4 carats worse, the report reading thus:—

GOLD REPORT.

		Carats.	Grains.
W^o	. . . . . .	4	...
Standard .	. . 22 Carats.		

The results of " parting " assays, in which both the gold and silver are determined, are reported in ounces of fine gold and silver in one pound troy, the abbreviations F.G. (fine

gold) and F.S. (fine silver) being very frequently employed
thus :—

Parting Assay Report.

	Oz.	Dwts.	Grs.
F.G.	8	10	6
F.S.	2	7	0

In pound troy.

The remaining 1 oz. 2 dwts. 18 grs. would be base metal,
probably copper. The results are also sometimes reported in
pennyweights per ounce.

The less cumbrous method of showing how many parts
of gold or silver are contained in 1000 parts of the alloy
is now universally adopted for all bullion assays, and will
no doubt in time replace the above methods for jewellers'
and goldsmiths' reports.

DISCUSSION.

Professor W. Gowland, F.R.S., Vice-President, in opening the discussion, thought the paper was not one which was likely to interest so many people as the previous paper which had been read, but nevertheless it was an extremely valuable one for the following reasons. Firstly, the information contained in it had never been published before, and could not therefore be obtained anywhere except in the paper; and secondly, because the author was specially fitted by training, and also by his experience as an assayer, for writing such a paper. The author was a son of Richard Smith, Dr. Percy's old assistant. In addition to the training under his father, the author had a thorough preparation at the Royal School of Mines for the work which he was now doing as assayer at the Sheffield Assay Office. With regard to the paper itself, the poor alloy which was in use in this country, and which was called 9 carat, *i.e.* only 375 per mil of gold, was, he thought, the lowest alloy that should be employed for jewellery; in fact, he would rather not employ that alloy at all, but one which was richer in gold. In Japan at the beginning of the last century a similar alloy was used, but unlike the British alloy, which consisted of gold, silver, copper, zinc, and what not alloys in many cases, it consisted simply of a gold and silver alloy. It was white, but by a very elaborate series of picklings the silver was removed from the surface of any object made of it, and a perfect gold surface was obtained. The objects when so pickled were indistinguishable from those of pure gold. With regard to the alloy in use at present in Japan for the coinage, the alloy was the same as the French and American, *i.e.* 9 parts of gold and 1 part of copper. But the Japanese did not like that alloy; they preferred the colour of the alloy which was generally known as British guinea gold, and therefore all their best jewellery was now made of that or a similar alloy. The alloy was high in gold, but the metals which were alloyed with it were copper and silver only. With regard to the alloys of gold and silver and gold and copper, to which allusion was made in the paper, when they were rich there was no segregation, and therefore there was no difficulty whatever in taking by a cutting a representative sample for assay, but with those alloys, especially the poor ones, used in jewellery, which consisted of gold, copper, &c., a great difficulty was experienced in taking a sample. An ingot or bar, poor in gold, and containing much copper, could not be assayed from a cutting; it must be first melted, and what was called a "dip" taken. A small quantity of the molten metal was taken out by a charcoal dipper, and it was only by that means that a sample could be obtained which represented the composition of the ingot. At the Goldsmiths' Hall and the Sheffield Assay Office articles of jewellery and plate were received in nearly a finished condition, and most ingenious methods were in operation for taking samples without really injuring them to such an extent that they could not be properly finished. Great difficulties had to be contended with, because all articles which were low in gold had been subjected to very severe pickling, and the surface was richer

than the layers below. Therefore it was absolutely necessary, as stated in the paper, to remove the whole of the upper surface where the assay piece was taken, and to take the assay piece only from the internal layers. With regard to the practical assay work of the Assay Office, the officials of course knew what the composition of the alloy was, and therefore it was very easy for them to make up what was called a "fire," *i.e.* in making up a batch of assays, they made up at the same time checks—pieces of metal which had the same composition as the metal that was being assayed. That, as the members well knew, was absolutely necessary in order to obtain a true and accurate assay. But when the metal consisted simply of an alloy that was high in gold, the other portion of the metal being silver, he found that in the Mint in Japan, when time was not available to make the preliminary assay, very accurate information as to the composition of a gold and silver alloy could be obtained by the very old-fashioned method of testing it with a touchstone. In fact, after he had prepared a proper series of alloys he became quite expert in determining the value of a sample by the touchstone, and was then able without a preliminary assay to make up a proper charge for cupellation. Another point with regard to methods of assaying upon which he laid very great stress was, that one of the most important conditions in a gold assay was the right temperature of the muffle. If the temperature of the muffle was not regular, and if it was too high, the assayer might have to discard the whole of his assays. With regard to poor gold alloys, where there was much copper it was necessary to use a considerable amount of lead. He found that the method mentioned in the paper was very similar to the one that he employed in dealing with very large quantities of such alloys which were received from mines. The procedure followed was to divide the lead into three portions. Two portions were in the form of balls of given weight, and one portion in the form of foil, in which the assay piece was wrapt up. In charging the assays into the cupels, one leaden ball was first charged in, and then the lead packet containing the alloy, and when the assay was nearly finished the other ball of lead was added. By adopting that procedure he found that the resulting button was much freer from copper than if the whole of the lead had been added at the beginning of the assay. In conclusion, he thought the Institute was very much indebted indeed to the author for bringing before it the results of his wide experience, and for having stated them so ably and clearly in his paper.

Professor T. TURNER, M.Sc., Honorary Treasurer, desired to endorse the remarks Professor Gowland had made in reference to the value of the paper, particularly with regard to the information contained in it. He had no doubt the paper would be regarded as one of value for reference by students for a long period to come. He wished to say a word or two from a personal point of view, because, as Professor Gowland had mentioned, the writer of the paper was the son of the late Mr. Richard Smith, who was for so many years the instructor in the Royal School of Mines, and to whom reference was so frequently made in the writings of Dr. Percy. As Richard Smith was his old teacher, and the teacher of a

great many other School of Mines' men who were scattered up and down the world, he was sure that the pupils of Richard Smith were very pleased indeed to see his son following in the lines of his father, and possessing so high a reputation in the metallurgical world in connection with the assay of the precious metals.

Mr. T. VAUGHAN HUGHES, Assoc. R.S.M. (Birmingham), after joining with the previous speakers in thanks to the author for his valuable paper, said he found that the author had omitted all reference to the cadmium alloys of low standard quality which were now used for soldering purposes. With regard to the method of procedure adopted in his own practice, he found it best to use 25 per cent. of lead, according to the weight of the assay, then charging the balance afterwards, and in all instances to use checks. Insistence had been laid on the use of checks. The way in which some assays were now made could, in his humble opinion, only lead to commercial disaster. He found that a great number of excellent men relied entirely upon their eyesight, and what they called their " better judgment," alleged to result from long experience in making assays of valuable materials, without using checks in the furnace. It had been shown in the paper there were very many variants over which there must be absolute control if accurate results were desired. While he was in British Columbia (B.C.) the legislature thought it wise to enact that all assayers should produce evidence of proper training before they were allowed to practise as assayers in that country. It certainly seemed to him that the time had arrived, as far as this country was concerned, when a similar line of action should be followed, because on looking through any one of the Annual Reports of the Royal Mint, it would be noticed that in the average results for various years of any of the gold alloys of Hall-marking quality, the actual gold present was in excess of that necessary to pass for Hall-marking. He thought that was largely due to the comparatively loose methods of assay that were adopted by the firms which were responsible for the supply of the raw material.

COMMUNICATIONS.

Mr. C. O. BANNISTER, Assoc. R.S.M. (London), wrote that he had read Mr. Smith's paper with much pleasure, and he considered it a most useful contribution to the study of the methods in use for the assay of gold alloys. The results collected and compared by Mr. Smith had hitherto been widely scattered and not easily obtainable. The nature of the cupels used throughout the determinations was not stated in the paper, but probably bone-ash cupels were used, as was commonly the practice in all cases in which checks were introduced ; magnesia cupels were now, however, being largely used, and possessed certain advantages over bone-ash cupels ; for example, there was less loss by absorption in the cupel owing to the surface being much smoother ; there was less loss

by volatilisation owing to the greater heat conductivity of the cupel, and therefore there was always found a larger surcharge when those cupels were used than those given in the paper. With alloys containing metals other than gold, silver, copper, and platinum, the magnesia cupels had distinct advantages. With regard to the method of taking samples, it was well known that a preliminary scraping was necessary to remove the surface or "colour" from gold wares, and Mr. Smith stated on p. 103 that "buffing" might be employed for that purpose. It would be of value to have some details as to the nature of the buff used for that purpose, as buffing was commonly employed in finishing articles, and was insufficient to remove the surface metal. In that connection it would be useful to know Mr. Smith's opinion as to the possibility in certain cases of taking an assay of the surface and then allowing for a certain enrichment of metal from a knowledge of the number of times an article had been fired and pickled.

In taking a sample by scraper it was also useful to remember the necessity of avoiding the solder used in the construction of the article, as it was possible in some cases to use a solder of higher gold contents than the main portion of the alloy, and a scraping taken over the solder would give a high result. It would be interesting to know if Mr. Smith had any figures available on the relative assay values of solders and the articles on which they were used.

On p. 107 the author seemed to infer that the use of less lead might result in obtaining well-formed, clean, and bright buttons when added in two portions. The writer suggested that that would be better read as follows : "well-formed, clean, and bright buttons may be obtained with less lead when the latter is added in two portions," for it seemed fairly certain that an excess of lead could have no injurious effect on the appearance of the remaining bullion. Although that method of adding lead in two separate portions was fairly largely used, it was by no means universally applicable ; for instance, in the assay of very small samples, taken by means of a scraper, the amount of bullion and lead used in the assay was so small that it would be unwise to attempt the addition of the lead in two portions.

Mr. W. F. Lowe (Chester) wrote that he was much interested in Mr. Smith's paper, which was full of valuable information, and as at the Chester Assay Office they daily made over 200 gold assays, it was a subject in which he had some practical experience.

The following were a few points that might be of interest :—

In sampling manufactured gold articles at Chester the "colour" was removed with revolving scratch brushes or buffs and a little emery powder. The brushes were hooded over and driven by an electric motor, and the metallic dust was sucked away by a small "Peerless" centrifugal fan, and was delivered into a dust separator and collector.

Articles of 0·375 and 0·5 standards were required to be fully up to the standard, including the solder, *i.e.* the solder used must be not less than 0·375 and 0·5 quality, and assays were specially made to include any solder, and with some of the small hollow articles the whole article

was melted down under charcoal, and portions of the melt taken for assay.

In charging the assays into the furnace a special charging tray was used, and 60 assays were dropped into the hot cupels by merely sliding out the bottom of the tray.

Mr. Smith had referred to a paper of the writer's published in the *Journal of the Society of Chemical Industry* in 1889. He (the writer) described in that paper the apparatus for parting used at Chester at that time, but they had now for many years used the platinum cups and trays, as they saved much time. From his notes he found that the assays in the old apparatus were more uniform and the correction for surcharge much less. In the platinum apparatus the surcharge on 0·9166 was usually + 0·26, for 0·75 from 0·0 to − 0·13, for 0·625 from 0·0 to − 0·13, and for 0·375 from − 0·52 to − 1·05 per 1000.

He noticed that Mr. Smith preferred to use rather more lead for the cupellation of the 0·375 assays, but he (the writer) had found that about 20 parts yielded a bright clean button that flattened well without cracks, and an extra quantity of lead only lengthened the time in the muffle. As to the addition of the lead in two portions he had a very strong objection to it, as there seemed little or nothing to be gained, with the danger of spoiling the whole batch of assays in the furnace, sixty in their case.

For check assays at Chester pure gold was used, as he thought it was safer for that purpose than the use of alloys. It was prepared by dissolving assay cornets in *aqua regia*, evaporating to dryness twice or three times to get rid of excess of acid, then diluting largely with water to allow the silver chloride to settle out. Next the clear solution was siphoned off and the remainder filtered, and the solution precipitated in the cold with SO_2 obtained from liquid SO_2. The precipitated gold was washed with water, dried, and fused in a fire-clay crucible with sufficient pure potassium bisulphate to cover it when molten ; it was allowed to set in the crucible, which was afterwards broken, and the gold cleaned from the slag and then flattened and rolled into a sheet. He had used that method for the last fifteen years, and had found it very satisfactory.

The check assays were made to correspond as nearly as possible to articles of the same standard by the addition of a suitable proportion of copper to each check.

Mr. F. C. Robinson (Sheffield) wrote that as one who had had many years experience in the assaying of industrial gold alloys, many of which had, after working and fashioning, come to the Sheffield Assay Office for the Hall-mark, he was desirous of contributing a few remarks on Mr. E. A. Smith's useful paper, which treated quite exhaustively a subject seldom discussed before our British societies. His standpoint, however, was a somewhat different one to the author's, as it was that of assaying the freshly cast bars of the ternary alloys of gold, silver, and copper, rather than conducting assays after rolling or working, sometimes (as indicated by the author) after mechanical treatment had produced extreme thinness. Thus, in practically every case, he (Mr. Robinson)

was able to weigh fully 0·5 grammes from one corner sample, and duplicates from the diagonal corner sample. There was, however, the same necessity, although not so urgent perhaps, of removing the surface from the flattened pieces, as the "colouring" due to pickling was quite appreciable. He fully endorsed Mr. Smith's emphasis on the necessity of using "checks," made up of known quantities of gold, silver, copper, &c., so as to be as near as possible similar to the assay, and agreed with his view that it was only when "great exactness is not required" that a piece of alloy of similar composition should be used for checks. Although the writer had never risked a trial of the latter method advocated by Dr. Rose, he preferred the weights of gold, silver, &c., in his checks to be, like Cæsar's wife, above suspicion.

Table V. was interesting as showing the variation in practice of different assayers with regard to the proportion of lead they added for cupellation. His preference was for the larger quantities, especially for the low quality gold alloys with high copper contents, as the nett surcharge on the gold was nearer nil, owing to the possibility of cupelling at lower temperatures. He believed that Mr. Smith did not call attention in his paper to the importance of cooling off as soon as possible after clearing a cupellation where much copper was present. Experience showed it to be easier, when more lead was used, to prevent the scoring of bone-ash cupels at the start by cooling off as soon as possible. The retention of minute beads by the rough places on the cupel was thus minimised and practically prevented. It was also found that smaller negative surcharges resulted, so that any small differences in the amount of base metals in checks and assays had no place in the final gold results, and that duplicate results certainly were more concordant.

The results of Mr. W. F. Lowe in Table VII., showing that the same weight of lead carried the same weight of gold into the cupel irrespective of the quality of gold alloy cupelled, were difficult to reconcile with the statement on the previous page, that "experience shows that an increase in the percentage of copper results in an increase in the loss of gold. The loss on the cupel is also dependent on the quantity of gold in the assay piece." It was due rather to the fact that more lead had to be used. Rossler was quoted to this effect just previously. It was an undeniable fact that copper could cause great losses of gold, but that might be due largely to the increased heat of cupellation necessary, a difficulty easily met by adding plenty of lead and adjusting the heat so as to cause the litharge to feather on the cupel. Then the loss due to the combined action of lead and copper was surprisingly small, and enabled assays on all kinds of material to be brought nearer to the uniform basis of small corrections. The writer held that many assayers had an unwise aversion to using plenty of lead in cupellation. The foregoing statements were in conflict with those of the author on p. 114, that "less silver is lost by cupelling at a higher temperature with a small quantity of lead than by employing more lead and working at a lower temperature." That might be the result of special experiments conducted by the author, whereas his (Mr. Robinson's) were founded upon ordinary observation.

I

With regard to reporting assays, any means of obtaining a uniform decimal system would be welcome. The public assay offices might make a start by being compelled by Act of Parliament to report only decimally in the case of these alloys.

Dr. T. K. Rose (Royal Mint, London) wrote that he considered the paper was one of very great value and interest. It showed an intimate acquaintance with the subject on the part of Mr. Smith, which was not surprising considering his long and varied experience in assaying the alloys of gold and silver.

The accuracy of the assay of gold alloys which were presented in various forms for Hall-marking was of great importance, and the details of the methods of examination had never been fully discussed.

The elimination of copper was a case in point. The prills for parting must be malleable, and should also be clean and bright in order to make sure that no insoluble foreign material was adhering to them. It was, therefore, necessary to remove most of the copper (and incidentally all the zinc, &c.) by cupellation, as otherwise the prills blacken on cooling. The exact proportion of copper which could be left in the prill without disadvantage had not been determined, and was not of practical importance, as, if the button was clean, it did not matter how much copper remained. The removal of copper, however, entailed an increase in the loss of gold by cupel absorption, and therefore as little as possible of the copper was eliminated.

In considering how this was to be done, it was easy to exaggerate the importance of the precise amount of lead to be used. In practice, any quantity less than about eight times the weight of the gold alloy (or say twice the weight of the inquarted alloy) was inconvenient because of the danger, experienced formerly at the French Mint, of beads being hung up on the cupel and separated from the remainder of the assay piece. The upper limit of the quantity of lead was also largely a matter of convenience, influenced by such things as length of time in working off, the size of the cupel, &c. It was hardly true to say that too much lead caused a high loss of gold. An increase in the amount of lead had very little effect on the loss of gold, as might be seen indeed in Tables XI. and XII. in the paper. For example, in Table XI., at the "medium temperature" the mean loss of gold with 30 parts of lead was 3·67 per 1000, and with 25 parts of lead, 5·86 per 1000. Table X. was not applicable, because the amount of copper varied.

Some years ago he (the writer) compared the effects of 4 parts, 8 parts, and 12 parts of lead on 22 carat gold, and found the results after parting to be identical. The cornets were weighed correct to 0·1 per 1000. It would, therefore, appear to be largely a matter of individual choice how much lead was used. In spite of D'Arcet and those who had copied his figures, there was little advantage in increasing the lead beyond about 20 times the weight of the alloy (Mr. Lowe's choice), because in a diluted mixture very little copper was oxidised. In fact, most of the copper was eliminated during the last stage of cupellation, just before the lead was worked off.

It was due to those considerations that the method of using successive doses of lead had been developed at the Royal Mint. The quantities of lead now used there were as follows :—

Standard.	Amount of lead used for one part of alloy.		
	Lead for 1st charge.	Lead for 2nd charge.	Total Lead.
916·6	8·0	...	8·0
750·0	8·0	...	8·0
625·0	8·0	4·0	12·0
500·0	8·0	8·0	16·0
375·0	8·0	8·0	16·0

The approximate surcharges were as follows :—

Standard.	Surcharge.
916·6	+0·6 per 1000.
750·0	+0·5 ,, ,,
625·0	+0·4 ,, ,,
500·0	0·0 ,, ,,
375·0	−0·6 ,, ,,

These tables were in accordance with modern practice, and superseded Table VI. and the third column of Table VIII. in Mr. Smith's paper. The quantities were convenient, and gave concordant results.

Mr. ERNEST A. SMITH wrote that before replying to the several points raised in the discussion, he wished to express his indebtedness to Professor W. Gowland, F.R.S., and to Professor T. Turner for the very kind references which they had made to the author's late father, Mr. Richard Smith, and to his success as a teacher during his long connection with the Royal School of Mines.

It was a source of pleasure to know that his work as one of the pioneer instructors in assaying in England was so much appreciated and valued by the many students who had passed under his instruction, and were now occupying important positions in all parts of the world.

In reply to the discussion, he was pleased to find that in the main his conclusions were approved, and he wished to thank all those who had contributed to the interesting and valuable discussion which the paper had evoked.

The author was quite in agreement with Professor Gowland that there was no surer method of obtaining a representative sample of a gold alloy, especially an alloy of low standard, than by taking a dip assay, *i.e.* a portion taken by a small ladle or dipper from a mass of metal while molten. He considered it was very desirable to adopt that method in the case of the impure alloys resulting from the treatment of lemel, &c., when the quantity of metal in the crucible was sufficient to allow of a dip sample being taken. When such a course could not be adopted

the samples had to be taken after casting by cutting or drilling the resulting bars in the manner described in the paper.

It might be remarked that some assayers sampled those alloys by pouring off a small portion of the metal after the molten mass had been well stirred and before casting the metal into an ingot mould.

The remarks of Professor Gowland on the alloys used in Japan for the purposes of coinage and jewellery were of interest as showing the universal adoption of the "pickling" process for the enrichment of the surface of gold alloys. The author was pleased to find that Professor Gowland endorsed the statement in the paper that the button from cupellation was freer from copper when successive charges of lead were made than when the whole of the lead was added at the beginning of the assay.

The author fully endorsed Professor Gowland's remarks, in which he emphasised the importance of having the muffle at the right temperature for cupellation. It was common experience that students and beginners in their anxiety to prevent "freezing" invariably cupelled at too high a temperature. What the correct temperature should be was entirely a matter of careful observation and experience, but it was well known that the results of gold assays were considerably influenced by the cupellation temperature. In that connection the following figures obtained by Mr. Beringer * were of interest, as showing the losses that might arise when a high temperature was employed :—

In three cupellations of one gramme of gold with 20 grammes of lead made purposely at a very high temperature, the cupel absorbed 6·04, 6·20, and 6·45 milligrammes of gold respectively. Hence at a high temperature there might easily be a loss of more than half of 1 per cent. of the gold. In ten cupellations, with the same quantities of gold and lead, but at an ordinary temperature, the gold recovered from the cupels varied from 1·37 to 1·92 milligrammes, and gave an average of 1·59 milligrammes. The average of those results showed the cupellation loss of pure gold under the conditions of the experiments to be about 0·15 per cent., or 1·5 parts per 1000.

In reply to Mr. T. Vaughan Hughes, the author was aware that alloys of low standard containing cadmium had been introduced recently for soldering purposes as the result of the new regulations relating to the use of gold solder issued by the Birmingham Assay Office in 1909, which required that

"Gold wares of the two lower standards, namely 9 carat and 12 carat, needing solder in the making shall, as a whole, as well as in every part thereof, assay at not less than the standard declared by the sender."

The time at the author's disposal, however, did not permit of an examination of these solders being made in time for inclusion in the paper, but it would appear that they were somewhat similar in composition to the ordinary low-standard gold solders, with the exception that they were of standard quality, and that part of the base metal

* *A Text-book of Assaying*, C. and J. J. Beringer.

present was replaced by a small percentage of cadmium to lower the melting point. With regard to some of the comparatively high results quoted from the Annual Reports of the Royal Mints, some of those were no doubt due, as suggested by Mr. Vaughan Hughes, to want of accuracy in making the assays, and also partly accounted for by the fact, mentioned in the paper, that all gold alloys, especially those of low standard, were subject to more or less segregation during solidification. To compensate for that unequal distribution of the constituent metals a slight excess of gold was added to ensure every part of the ingot being of standard quality.

It might also be pointed out that during the mechanical treatment and annealing to which the metal was subjected in the course of manufacture, oxide and dirt were driven into the surface and are not entirely removed by pickling. Under those conditions it was often very difficult in sampling sheet metal by scraping to obtain a sample quite free from such impurities, even after the surface had been cleaned by a preliminary scraping.

If the alloys were made exactly to the required standard, it was obvious that under the above conditions there would be considerable risk of delay when gold wares were submitted for Hall-marking, as the wares would in all probability be detained for retrial through the Assay authorities not being able to secure a satisfactory sample in the first instance.

With reference to the question of cupels raised by Mr. Bannister, it might be stated that bone-ash cupels were used for all the determinations recorded in the paper, a large proportion of the work being done on the well-known Deleuil French cupels, which, in the author's opinion, were excellent for all bullion assays. The relative merits of bone-ash and magnesia cupels mentioned by Mr. Bannister, and recorded more fully in his valuable paper recently read before the Institution of Mining and Metallurgy, were of special interest in view of the fact that many assayers were now using magnesia cupels. As the conditions of cupellation with magnesia cupels differed from those of bone-ash cupels, it will be very necessary in all future experimental work dealing with cupellation to state what cupels were used.

With regard to the removal of "colour" by buffing, Mr. Bannister would find his question fully answered by Mr. Lowe in his contribution to the discussion. It was of course important in sampling gold wares to avoid including solder in the sample. When there was any doubt as to the existence of solder, its presence could usually be ascertained by carefully heating the article over a Bunsen flame, when any solder would be revealed owing to the difference in colour of the oxidised surface compared with that of the alloy of which the article was composed. He was obliged to Mr. Bannister for the suggested rendering of the sentence on p. 107, which was perhaps an improvement and more clearly described the facts.

With regard to the method of adding the lead in two portions, he agreed with Mr. Bannister that it was by no means universally applicable, and it had been pointed out in the paper that it can only be applied

in cases where the quantity of lead was sufficient to allow of this method being conveniently adopted.

Mr. Lowe's figures for the surcharges obtained at the Chester Assay Office were very useful, as they superseded those quoted in the paper. The method of preparing pure gold for check purposes, described by Mr. Lowe, was the one used by the author and also at the Royal Mint *
and other assay offices.

When every precaution was taken in the preparation of proof gold by that method, the resulting metal was of a very high degree of purity ; but what the exact degree of purity was it was very difficult to ascertain, as it was doubtful whether absolutely pure gold, which could be used for the purposes of comparison, had ever been obtained.

For all practical purposes assayers regarded the gold prepared by that method as absolutely pure—*i.e.* 1000 fine ; but in cases where a very high degree of accuracy was desired, it would no doubt be a very close approximation to the true purity of the metal to state the fineness as 999·9 per 1000.

The remarks contributed by Mr. F. C. Robinson, Chief Assayer of the well-known Sheffield Smelting Company, called for careful consideration in view of his wide experience in assaying the various alloys dealt with in the paper. The author was not, however, in agreement with him in advocating the use of larger quantities of lead than those given in the several Tables in the paper. It was true that the proportion of lead to be used for the assay of the ternary alloys of gold, silver, and copper was, as remarked by Dr. Rose, largely a matter of individual choice ; but from the experiments of D'Arcet and others, it seemed fairly conclusive that a quantity of lead equal to thirty-four times the weight of the sample taken was sufficient even when the gold was alloyed entirely with copper. And when it was remembered that silver also formed a constituent of the majority of the industrial alloys, and that its presence facilitated the removal of the copper, it would appear that less lead than thirty-four times would suffice in a large majority of cases, and to use any proportion beyond that would be purely a waste of time and material. In discussing the question of lead, it should be borne in mind that a smaller quantity of lead would suffice for assays in which parting silver was added than for those in which a weighed quantity of alloy was cupelled direct without any addition of silver. That silver had a marked influence, even when copper was absent, was shown by the results of experiments by Mr. Beringer. Three lots of gold (0·3 gramme each) were cupelled with 10 grammes of lead and varying amounts of silver, and the cupels were assayed for gold with the following results :—

Gold taken up	.	.	0·3 gramme.	0·3 gramme.	0·3 gramme.
Silver added	.	.	0·3 ,,	0·6 ,,	0·9 ,,
Gold in the cupel	.		0·47 milligramme.	0·32 milligramme.	0·17 milligramme.

These, calculated on the 0·3 gramme of gold, gave the loss as 0·157, 0·107, and 0·057 per cent. respectively.

* *Metallurgy of Gold*, T. K. Rose.

It was essential, in the class of assays dealt with in the paper, to employ a quantity of lead sufficient to eliminate the copper as far as possible, and this might always be ensured by using the maximum quantity of lead; but as the loss of silver increased with the length of the time of cupellation, it was indispensable to reduce the loss as much as possible by reducing the proportion of lead to that which was strictly necessary.

The various Tables given in the paper showed that the cupellation results of ternary alloys were considerably influenced by the quantity of lead and by the temperature of cupellation, and by varying those almost any result might be obtained. The author would submit that, on the one hand, by using a large quantity of lead, the loss of silver was increased; and on the other that, by working at the low temperature at which the litharge "feathered," less copper was likely to be eliminated. Bearing in mind those two facts, it was of course possible, under the special conditions found by experience to be best suited to the cupellation of any particular class of alloys, that the copper retained by the gold-silver buttons just compensated for the loss of silver, and gave results which "are brought nearer to the uniform basis of small corrections;" but long experience proved that the amount of copper retained was so variable and so dependent on working conditions, that that error could not be considered in every case exactly to compensate the loss of silver. The author's experience with low temperature cupellations in the case of gold alloys containing copper, was that the final buttons retained more copper, were flatter, and were not so readily detached from the cupel. With regard to the statement quoted from p. 114, that was based on several years' experience with all classes of commercial alloys and confirmed by experiment. The statement must of necessity be qualified to suit the particular class of alloy being assayed.

Mr. Robinson had doubted whether the losses given in Table VII. could be attributed to the presence of copper, and suggested that they were more probably accounted for by the differences in the ratios of the lead to the gold in the assay piece and also to a high cupellation temperature.

It was well known that the predominant cause of the gold loss during cupellation was the solution of the metal in the molten litharge which

Action of Copper in Cupellation of Gold.

Weight of Gold used.	Lead Used.	Copper Added to Lead.	Ratio Lead to Copper.	Cupellation Loss.
Milligrammes.	Grammes.	Per Cent.		Per Cent.
202	10	...	...	0·155
202	10	0·1	1000 to 1	0·19 ⎫
201	10	0·2	500 to 1	0·20 ⎬ *
200	10	0·3	333 to 1	0·13 ⎭
201	10	0·4	250 to 1	0·165
202	10	0·5	200 to 1	0·250

* These are the actual losses. All the buttons retained copper to the extent of 0·16 per cent.

passed into the cupel, and long experience had proved that when copper was present the absorption was greater.

The influence of small amounts of copper on the cupellation of gold had been ascertained by Lodge,* and his results were as follows: The cupellation temperature was 775° C., a little above that required to keep the litharge melted, and it had been proved that that could be attained by maintaining the temperature at 650° C.–750° C.

Those results confirmed the statement made in the paper, "that an increase in the percentage of copper results in an increase in the loss of gold."

With reference to Table VII., it might be pointed out that the figures in the third column also confirm the statement. In the case of the first alloy, containing 916·6 parts of gold per 1000 and 83·4 parts of copper, the cupel absorption was 0·70, which represented a loss on the actual gold present of 0·765 parts per 1000.

In the case of the last alloy, containing only 375·0 parts of gold per 1000 and a much larger proportion of copper, the cupel absorption was also 0·70, but this represented on the actual gold present a loss of 1·866 parts per 1000, about two and a half times greater, which was undoubtedly due to the increased proportion of copper. As the result of experience there was little doubt that the effect of copper was to increase the cupellation loss, "which, silver being absent, may from this cause rise to 0·3 per cent., even when the temperature is not excessive."

It was well known that the cupellation losses were influenced by the amount of lead used and by the temperature of cupellation, and the author had already drawn attention to those facts; but in his opinion the losses under those two heads were, under normal conditions of working, small, and would not account for the comparatively large losses which invariably took place when copper was present.

The working conditions in Beringer's experiments, quoted above by the author, resulted in a cupellation loss in the case of pure gold of 1·5 per 1000, but in actual practice the loss was frequently found to be about one-half this amount—viz. 0·7 per 1000. Dr. Rose gave the cupellation loss on the assay of standard gold (916·6 fine) at the Royal Mint as varying from 0·4 to 0·8 per 1000.

The question of the elimination of copper during cupellation was of considerable interest. When copper was present the cupellation temperature must be a little higher to prevent "freezing," as the freezing points of alloys of the lead-copper series were higher than that of pure lead; for example, an alloy containing 10 per cent. of copper and 90 per cent. lead froze at 900° C. Copper did not oxidise as readily as lead, and, as pointed out by Dr. Rose in his contribution to the discussion, very little copper was oxidised in a diluted mixture of lead and copper. During cupellation copper tended to concentrate in the molten metal, and consequently most of it was eliminated during the last stages of cupellation. The tenacity with which a small quantity of copper was

* *Notes on Assaying*, p. 143.

retained with the gold and silver was probably due to the fact that the copper oxide in contact with the metallic lead was reduced to copper, which alloys again with the precious metals, and finally remains with the metal left on the cupel.

Although the author had not specially drawn attention to the necessity of lowering the muffle temperature after the lead had "cleared" at the start of the cupellation, he was in agreement with Mr. Robinson in emphasising the point. On the other hand, great care should be taken to ensure that the heat was so high before "charging in" that the chilling which necessarily took place during that operation should not cool the muffle below the requisite temperature. Mr. Robinson had drawn attention to the "scoring" or corrosive action of the copper oxide on the surface of the cupel : the author had not experienced any difficulty in that direction except in the case of cupels made from bone ash of inferior quality.

Dr. Rose's remarks were extremely valuable, and the author was obliged to him for the figures showing the quantities of lead now in use at the Royal Mint, and for the approximate surcharges on the legal standard alloys, to supersede those given in Table VI.

With regard to the question of the loss of gold by an increase of lead, the results in Table XI. were not altogether applicable, as the figures related to the gold-silver button left on the cupel from ternary alloys and not to pure gold.

It was admitted that in the cupellation of comparatively pure gold the loss of gold due to increased lead was very small, provided the temperature of cupellation was properly regulated, but experience showed that it slightly increased with large increases of lead, as stated in the paper.

It should be mentioned that the "surcharges" given in Tables X., XI., XII. referred to the losses or gains on the gold-silver buttons left on the cupels, and not, as was generally understood by the term, to the gold cornets after parting in acid.

THE ANALYSIS OF ALUMINIUM AND ITS ALLOYS

By RICHARD SELIGMAN, Ph.Nat.D., and F. J. WILLOTT.

INTRODUCTORY.

Now that aluminium is rapidly becoming one of the common metals, it is highly desirable that everything appertaining to it should be standardised as soon as possible.   Much work is in progress which will tend to bring this end about, but there is still a great deal to be done in this direction.   One of the cases where we ourselves have often felt the want of uniform practice among those who deal with aluminium, has been that of the analytical methods to be applied to the metal and its alloys, and it has seemed to us that if all the users could be induced to adopt a standard method, some of the difficulties which we have from time to time encountered would be removed.

That it is too early to lay down any such standard we recognise, and in bringing before this Institute the methods which we have used for a number of years, we are led by the hope that others will be induced to do the same, and that the discussion which will undoubtedly ensue may furnish the material on which the standard may at some future time be based.

Our analytical work has been mainly commercial, so that the methods which we shall describe will be for the most part the rapid methods of the industrial laboratory, and are designed to give only that degree of accuracy which the industry demands.

We propose to deal first with the pure metal, and subsequently with the more common of the aluminium alloys.

IMPURITIES CONTAINED IN " PURE " ALUMINIUM.

The vast majority of the aluminium of commerce contains as impurities silicon, iron, and sodium, together with minute traces of carbon, oxygen, and nitrogen, which have scarcely been determined with satisfactory accuracy. The products of some factories also regularly carry small amounts of copper, derived, no doubt, from certain parts of the furnace equipment used in the manufacture of the metal. In the following table (I.) a few characteristic analyses are given, which show the proportions in which these impurities usually occur in commercial aluminium. It will be seen that the relations between the chief ingredients vary in the products of various factories, although the total amount does not differ appreciably :—

TABLE I.

	Extra Pure Metal.	Ordinary American.	Ordinary English.	Ordinary French.	Low Grade.
Silicon . .	0·20	0·4	0·3	0·4	0·7
Iron . .	0·15	0·35	0·4	0·3	0·6
Sodium . .	0·02	...	0·04*	...	0·06
Copper . .	nil	0·1	nil	nil	nil

The statement of Echevarri * that only 0·003 per cent. of sodium is found in English metal must, we think, be due to an error. We have never come across metal containing so small an amount. With regard to carbon, nitrogen, and oxygen, we have no reliable data. Moissan found as much as 0·41 per cent. of carbon in American metal in 1898, whereas Dr. Caspari found not more than 0·01 per cent. in English metal in 1907, and sometimes none at all.

Of nitrogen we have not met with more than 0·001 per cent., whereas Dr. Caspari found as much as 0·0055 per cent.

The only data available as to the amount of oxygen in aluminium are contained in an article by Kohn-Abrest,† who

* *Journal of the Institute of Metals*, 1909, No. I. p. 127. A new method of analysis devised since these notes were compiled has shown us that this figure is somewhat high ; 0·03 would be a more average figure.

† *Bulletin of the Société Chimique*, 1909, vol. iv. p. 207.

gives about 2·3 per cent. as the amount in some samples of aluminium powder which he was examining. In other forms of the metal, such as sheets, bars, or castings, which present far less surface, the proportion of oxygen must be very much smaller than this. On the other hand, metal which has been seriously overheated may doubtless contain appreciable quantities.

General Remarks as to the Methods used.

In analysing aluminium, we have for a long time renounced the idea of determining the proportion of the metal itself, owing to the great difficulty of estimating the latter with any approach to accuracy in samples containing as much as 99·5 per cent., or even over 99·75 per cent. of this ingredient, a proportion of which may be in the form of oxide. Although, as was pointed out by Professor Carpenter,* this is regrettable from a scientific point of view, from a practical standpoint it has not, up to the present, been of much importance. Whilst it is true that an accurate estimation of the amount of aluminium would form a useful check on the determination of the impurities, it is the amount and relative proportions of the latter which affect the properties of the metal. Consequently we have usually confined our attention to the estimation of the impurities. In most works it has become customary to curtail even this operation, and to determine only those impurities present in appreciable quantities, and to call the balance aluminium. Thus the grade of metal known as 99·5 per cent. will, in most cases, contain about 0·5 per cent. of silicon and iron, so that in reality it will only carry about 99·4 per cent. of aluminium. This innocent deception has doubtless been fostered by our general ignorance as to the influence on the behaviour of the metal of the small quantities of impurities thus ignored ; but it seems to us that, as aluminium comes more widely into use, opportunities which have thus far been wanting, of filling some of these gaps in our knowledge, should present themselves, so that new and better methods of estimating the minor impurities will have to be devised.

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* *Proceedings of the Institution of Mechanical Engineers*, 1907, p. 97.

Analysis of "Pure" Aluminium.

Silicon.—Silicon appears to be present in aluminium in two, or possibly three, forms: viz. (1) combined as silicide of aluminium, or perhaps as an alumino silicide of iron; [*] (2) in the form of graphitic silicon (the condition of this material appears to vary according to the treatment to which the metal has been subjected); (3) Kohn-Abrest states [†] that he has found considerable quantities of silica in the samples upon which he was working, although it does not seem certain to us that this silica was not derived from the combined silicon during the course of the analysis.

As nothing is known at present as to the individual effect of these various forms of silicon on the properties of the metal, it is seldom found necessary to determine them separately, and the usual analysis consists in estimating only the total silicon. We will therefore first describe our method for doing this, which consists in removing the other ingredients by means of acids.

Total Silicon.—For this purpose 1 gramme of turnings, or chippings, are placed in a covered, wide form, 400 cubic centimetres beaker; 5 cubic centimetres of conc. HNO_3 are added, and subsequently 20 to 25 cubic centimetres of 25 per cent. H_2SO_4 and sufficient conc. HCl to effect solution (the amount depends on the purity of the metal and the fineness of the turnings). If the HNO_3 is omitted, as recommended by Moissan,[‡] a certain amount of silicon escapes as silicon hydride. We have found that the loss incurred in this way may amount to from 3 to 5 per cent. of the silicon present.[§] Figures illustrating this point are given in Table IV.

As soon as the HCl has been added, violent evolution of gas takes place, and if the turnings are very fine there is danger of the liquid foaming over. When solution is complete the sides of the beaker and the cover are washed down,

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[*] Vigouroux, *Comptes rendus*, 1905, vol. cxli. p. 951.
[†] *Loc. cit.*, p. 212.   [‡] *Comptes rendus*, 1895, vol. cxxi. p. 851.
[§] *Cf.* Sibbers, *Pharm. Zeitung*, 1897, vol. xlii. p. 622.

the latter removed, and the contents of the beaker evapor-
ated down slowly until aluminium sulphate begins to separate
out, when the beaker is again covered to prevent all risk of
loss by spitting.   To ensure that all the silica has been
rendered insoluble, the heating is continued until fumes are
freely disengaged and no moisture condenses on the cover.
The contents of the beaker are then allowed to cool, diluted
with 200 cubic centimetres of water and boiled until every
trace of aluminium sulphate has passed into solution ; but pro-
longed boiling, by which traces of silica might be dissolved,
should be avoided.   Some little experience is necessary before
the operator can recognise the correct point with certainty by
the disappearance of the satiny shimmer of the undissolved
sulphates, but in cases of doubt a little HCl may be added
to ensure the removal of the last traces.

The silica and silicon are subsequently removed by filtra-
tion.   Some care is necessary in the selection of a suitable
filter-paper ; C. Schleicher and Schüll's No. 589, Black Band,
has been found satisfactory.   If too dense a paper is
chosen the solutions filter very slowly, and there is great
difficulty in washing.   On the other hand, the fine graphitic
silicon may run through papers with unduly open texture,
especially when derived from low grade metal containing
about 1 per cent. of silicon.   This latter difficulty may also
obtain in the analysis of very hard worked metal.   We have
already pointed out that the condition of the silicon appears
to depend upon the treatment to which the metal has been
subjected, and in hard worked metal it is usually very finely
divided and more deeply coloured.

If necessary this drawback may be removed by annealing
the sample prior to analysis, but where this is not sufficient,
as is sometimes the case with samples containing large pro-
portions of graphitic silicon, a little paper pulp thrown on to
the filter proves effective.

After very careful washing, the mixture of silicon and
silica is strongly ignited over a burner until the con-
stancy of the weight indicates the complete conversion of the
silicon into silica.   This process may sometimes be unduly
prolonged, especially in the case of heavily worked metal.

In fact, where the amount of silicon is at all high it is necessary, for absolute accuracy, to fuse the mixture with alkaline carbonates and to reprecipitate the silicon, now wholly converted to silica, in the usual way with acid. For commercial purposes, however, the conversion into silica may often be dispensed with and the assumption made that all the silicon is present as oxide. The error thus introduced depends on the proportion of the graphitic silicon in the sample, but even in extreme cases this rarely amounts to 10 per cent. of the whole. It follows therefore that with ordinary high grade metal containing about 0·4 per cent. of silicon, the error is frequently of no importance from a commercial point of view.

Where absolute accuracy is required, the fusing of the residue is also desirable, because the latter may contain traces of iron, alumina, &c.

The following Table II. shows by a few typical examples the effect of fusing the residues and the error introduced by its omission. Table III. shows the degree of concordance which may be obtained by the method described above.

TABLE II.

Sample No.		Silicon found Assuming no Graphitic Silicon in Residue.	True Silicon found after Fusing the Residue.
1	. . . .	0·76	0·79
2	. . . .	0·73	0·76
3	. . . .	0·62	0·66
4	. . . .	0·56	0·56
5	. . . .	0·43	0·44

TABLE III.

Sample No. 1, Silicon per Cent. = 0·27, 0·27, 0·28, 0·27
    ,,   2,   ,,   ,,   = 0·41, 0·43*
    ,,   3,   ,,   ,,   = 0·46, 0·46, 0·46*
    ,,   4,   ,,   ,,   = 0·32, 0·33
    ,,   5,   ,,   ,,   = 0·41, 0·41
    ,,   6,   ,,   ,,   = 0·39, 0·38

Graphitic Silicon.—In cases where we have been desirous of differentiating between the combined and the graphitic silicon, we have omitted the HNO_3 when dissolving the original sample for fear of oxidising part of the finely divided silicon.

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* In the case of No. 2 the precipitate was very dark, indicating the presence of much silicon, whereas in the case of No. 3 it was quite white.

Where it is desirable to avoid the loss of the small amount of silicon hydride which is evolved under these conditions (see above), the solution is carried out in a flask and the gases evolved are passed, first through a spray trap, then through two U tubes containing bromine water, and finally through ammonia water.   By these precautions all the SiH_4 is retained, and may be recovered as silica by evaporating down the washing solutions.

The main solution, containing all the graphitic silicon and the bulk of the combined silicon in the form of silicic acid, is evaporated down and taken up again as in the determination of the total silicon.   In this case, however, the precipitate is filtered on to a tarred "platinum felt filter" carefully prepared as described by Hunt, Clapp, and Handy,[*] thoroughly washed and slowly dried until its weight is constant.   To the weight thus obtained the weight of the volatilised silicon is added after converting this latter figure into its silica equivalent.   In this way the weight of silicon + the weight of the silica is obtained, and from this figure and that of the total silicon the proportion of graphitic silicon can be calculated with fair accuracy.   The precipitate on the platinum filter may contain traces of iron and alumina, but these will be extremely small.   In Table IV. figures are given which show the amount of silicon volatilised in various samples and the effect of the addition of HNO_3.

TABLE IV.

Sample No.			Silicon in Dissolving Flask, no HNO_3 Used.		Silicon in Washing Train.	Total Silicon Using HNO_3.
1	.	.	0·717	+	0·043=0·76	0·79
2	.	.	0·751	+	0·041=0·79	0·81
3	.	.	0·627	+	0·035=0·66	0·66
4	.	.	0·546	+	0·018=0·56	0·57
5	.	.	0·417	+	0·023=0·44	0·45

Iron.—For the determination of the iron in aluminium we have used the method first described by Regelsberger,[†] which we have modified only in details.   Essentially this method consists in dissolving the aluminium in caustic soda, the iron

[*] *Chemical News*, 1892, vol. lxv. pp. 223, 235.
[†] *Zeitschrift für angew. Chem.*, 1891.

in sulphuric acid, and in titrating with permanganate. In practised hands it is very accurate, but careful attention to details is necessary if reliable results are to be obtained. Table V. shows the concordance of the results of which this method is capable :—

<div align="center">

TABLE V.

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Sample No. 1, Iron per Cent. = 0·40, 0·41, 0·40, 0·40
    ,,   2,   ,,   ,,   = 0·33, 0·33
    ,,   3,   ,,   ,,   = 0·36, 0·36, 0·37
    ,,   4,   ,,   ,,   = 0·28, 0·29
    ,,   5,   ,,   ,,   = 0·35, 0·34

For this determination the nature of the turnings which form the sample is of importance, unduly coarse material giving low results, whilst excessively fine turnings, powder, &c., cause the solution to foam. With a milling cutter very satisfactory samples can be produced. One gramme of the material is placed in a 400 cubic centimetres conical flask, lightly closed by a small funnel which acts as a valve. To this are added 25 cubic centimetres of a 25 per cent. caustic soda solution. The caustic must be free, not only from iron, but also from organic matter, chlorine, &c., which would interfere with the end-point of the permanganate used for the subsequent titration. We have found most of the brands of "sodium hydrate pure by alcohol" quite satisfactory, the only drawback being their high cost. If the turnings are not too coarse solution takes place rapidly, the iron being left unattacked, but if the sample contains any lumps they dissolve slowly, and there is danger of some of the iron oxidising before solution is complete. As soon as the reaction ceases, slightly more warm H_2SO_4 (25 per cent.) is run in than is required to give a clear solution. During this process violent ebullition takes place, and the iron dissolves to ferrous sulphate. The contents of the flask are now rapidly cooled. If copper is present it remains undissolved, and must be removed by rapid filtration through an open-textured paper. The iron is then determined by titration with permanganate solution, of which 1 cubic centimetre corresponds to 0·001 gramme of iron.

Sodium.[*]—For the determination of the sodium in aluminium

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[*] Since these notes were written we have developed new and better methods of determining sodium in aluminium, but as our work is not complete we cannot include an account of it here.

we take advantage of the fact that aluminium nitrate is decomposed at a temperature of about 250° C., giving insoluble alumina.*

Fifty cubic centimetres of strong HNO_3 are added to 3 to 5 grammes of turnings in a covered porcelain dish. Moissan † found it possible· to obtain solution by the aid of nitric acid alone, but owing to its enhanced purity, the metal of to-day is so slowly attacked by this acid that we find it necessary in most cases to add hydrochloric acid in small quantities until solution is complete. When this is the case the liquid is slowly evaporated down to dryness, the residue broken with a rod and moistened with nitric acid, which is again driven off to remove the last traces of hydrochloric acid. The decomposition of the aluminium nitrate which now follows is preferably carried out in a platinum dish, but with due care a porcelain basin may be used. When dry the crystalline mass is crushed and the temperature gradually raised, stirring and crushing being repeated at intervals until the evolution of nitrous fumes ceases. After allowing to cool, boiling water is added and the dish heated for a time over a burner. The liquid is then decanted on to a filter and the precipitate washed twice by decantation, and finally on the filter. The filtrate and washings are evaporated to dryness, again heated and, when cool, dissolved in 20 to 30 cubic centimetres of hot water, to which a few drops of ammonium carbonate have been added. After allowing to stand for a few minutes so as to allow any alumina which may have been left to separate out, the solution is filtered, evaporated to dryness in a weighed platinum dish, converted to chloride or sulphate, and weighed as such. It is advisable to run a blank at the same time as a genuine determination, because even with the greatest precautions a certain amount of sodium almost invariably finds its way into the solutions during the protracted operations described. Sometimes the error amounts to from 15 to 20 per cent. of the very small quantity of sodium really present.

Copper.—The presence of large quantities of copper is de-

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* Deville, *Annales de Chimie et de Physique*, 1853, vol. iii. p. 38.
† *Loc. cit.*

tected during the determination of the iron as described above. To insure the absence of traces, sulphuretted hydrogen is passed through the filtrate from the silicon. We shall refer to the estimation of copper when dealing with alloys.

ALLOYS.

Usual Composition.—The alloys of aluminium in common use contain, in addition to the ingredients already cited as impurities, copper, zinc, and nickel; more rarely magnesium, and as an additional impurity, lead. Alloys with tin are met with from time to time, usually in solders or soldered joints, whilst occasionally manganese, titanium, and tungsten have to be dealt with.

For the determination of these ingredients the ordinary methods are usually applicable, modified where necessitated by the large proportion of aluminium with which they are mixed.

Copper.—For the estimation of copper in " heavy alloys " containing 90 per cent. and upwards of this material, no special method is necessary. These alloys dissolve rapidly in nitric acid, and the copper may be deposited by electrolysis or as sulphide, &c. The light alloys, however, containing about 6 per cent. of copper, dissolve very slowly in nitric acid, and the precipitate obtained from their solutions by electrolysis is contaminated by alumina. We therefore pass sulphuretted hydrogen through the filtrate from the silicon and silica, and estimate the copper by the customary methods in the precipitate so obtained.

Zinc and Nickel.—Zinc * and nickel may both be determined in the same sample.† For this purpose 0·5 to 1 gramme of turnings are dissolved in a 400 cubic centimetres beaker in 25 cubic centimetres of 25 per cent. caustic soda, and the contents of the beaker subsequently diluted to about 300 cubic centimetres. The residue, consisting of the nickel, together

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* When these notes were written we had not seen Messrs. Greenwood and Brislee's paper, and we have not yet had an opportunity of testing the method recommended by these workers.

† Seligman and Willott, *Society of Chemical Industry*, 1905, vol. xxiv. p. 1278.

with iron, &c., is removed by filtration and dissolved in hydro-chloric acid, with the addition, if necessary, of a few drops of nitric acid. The filtration should be carried out without undue loss of time, as otherwise some difficulty may be experienced owing to the iron oxidising and running through the filter. If copper is present it must be removed with sulphuretted hydrogen, and the excess of the latter driven off by boiling. After diluting the acid solution to 200 cubic centimetres with hot water, the nickel is reprecipitated with caustic soda, a few drops of bromine water are added and the solution is boiled. The resulting precipitate is again removed by filtration and washed, the filtrate being added to that obtained in the first instance. In the precipitate the nickel is determined according to the usual methods.

Zinc.—The combined filtrates, containing the aluminium and the zinc, are treated with H_2S until alumina commences to be deposited, a condition which may be recognised by the formation of a skin over the gas bubbles as they reach the surface of the liquid. The presence of a small amount of alumina in the zinc precipitate is innocuous. The zinc sulphide is removed by filtration but is not washed. Subsequently it is redissolved in the same beaker in as little hydrochloric acid as possible, and 2 cubic centimetres of concentrated acid are added in excess. The solution is then diluted to 250 cubic centimetres with hot water, and 5 grammes of ammonium chloride are added. If no tin is present the zinc is at once determined by titration with standard ferrocyanide solution,* but in the presence of tin the titration must be preceded by the passing of H_2S through the solution.

Aluminium.—Aluminium is usually precipitated from the solutions of the heavy alloys as phosphate or hydrate. When as the latter the precipitate is washed with an ammonium nitrate solution containing a few drops of free ammonia, as slightly low results are obtained when pure water is used.

Lead.—This element is never present in large quantities in the light alloys, but is nearly always introduced as an impurity with zinc. It is brought down as sulphate with the silica during the determination of the latter, so that a closer-

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* See Nissenson and Kettenbeil, *Chemiker Zeitung*, 1905, vol. lxxiii. p. 591.

textured paper must be used for filtration, and this may occasionally necessitate filtering by the aid of a pump. (The silicon contained in aluminium appears to undergo some change when the latter is combined with other metals, as the alloys are found to contain very little or no graphitic silicon. The filtering is therefore rarely so difficult as with the silicon derived from " pure " metal.)

RARE ALLOYS.

Before closing we will refer very briefly to our methods for determining a few of the less common ingredients which are occasionally met with in aluminium alloys. We shall only do so in so far as any special operations are necessitated by the peculiar nature of these alloys. We are encouraged to this course by the consideration that rare though these alloys may be at the moment, the systematic study to which they are being subjected will almost certainly increase their importance.

Tin.—Tin is rarely met with except in solders. The only point of interest lies in the method of dissolving the samples which is affected by hydrochloric acid and, if necessary, potassium chlorate. Subsequently the tin is reduced and then titrated with iodine.

Magnesium.—For the determination of the magnesium the sample is dissolved in hydrochloric acid, a little nitric acid being added if a black residue remain. If copper is present it must now be removed by sulphuretted hydrogen. The iron and alumina are then precipitated as basic acetates. In order to obviate the tedious washing of this precipitate, the liquid is made up to known volume, allowed to clear by standing, and the clear solution decanted through a dry filter. Nitric acid is added to a measured portion of the filtrate, which is then boiled down to a convenient bulk and the magnesium precipitated as magnesium ammonium phosphate. If zinc, manganese, or nickel are present, the measured volume of the filtrate from the basic acetates must be made alkaline and treated with sulphuretted hydrogen before the addition of nitric acid.

Titanium.—Titanium may be estimated colorimetrically in

the filtrate from the silicon, using the hydrogen peroxide method.*

Manganese.—If the alloy is soluble in nitric acid, the manganese may be determined by the bismuthate method as described by Ibbotson and Brearly.† If the fine turnings are not soluble in nitric acid, aqua regia must be used, the hydrochloric acid which would interfere with the reaction being removed by evaporating down the solution with sulphuric acid.

Tungsten.—The sample is dissolved in just sufficient hydrochloric acid to effect solution when, if the residue is dark, a little nitric acid is added to decolorise it. The solution is diluted to 200 cubic centimetres, sodium hydrate added in excess, and the contents of the beaker boiled and filtered. The filtrate containing the tungsten and aluminium is poured slowly, with constant stirring, into boiling hydrochloric acid (3HCl : 1H$_2$O), of which sufficient is taken to leave about 15 cubic centimetres in excess at the end of the operation. The resulting liquid is slowly evaporated to about 300 cubic centimetres and the precipitate filtered off, the filtrate being boiled again to insure that all the tungstic acid has been precipitated. The latter is then ignited and weighed. If the degree of accuracy required renders it necessary, the tungstic acid is freed from silica by treatment with hydrofluoric acid after the ignition.

* Hillebrand, *Chemical News*, vol. lxxxiii. p. 177.
† *Chemical News*, vol. lxxxiv. p. 247.

DISCUSSION.

Mr. G. A. BOEDDICKER, Member of Council, in opening the discussion on Messrs. Seligman and Willott's paper, said that he considered in the estimation of silica and silicon it was absolutely necessary in every case to examine the silica after weighing, even if it had been precipitated twice, by treating it with hydrofluoric acid. In his own experience he had never found silica which was absolutely pure, however carefully it had been separated. In every other respect he thought the paper was admirable. It gave particulars of a great many methods for the estimation of nearly every impurity, and the methods were clearly set forth, so that even those who had not much experience in such analyses could hope to obtain adequate results.

Dr. G. H. BAILEY (Kinlochleven, N.B.) said that whilst admiring the contents of the paper, and being in a position to admit it was an extremely good account, as had been already said by Dr. Boeddicker, of the methods of analysis of aluminium, he confessed to a little disappointment that in one or two respects it fell short of an ideal which he personally would have placed before himself. In the first place, there was a statement in the paper to the effect that it was desirable that a standard method for analysis of aluminium, as with other metals, should be arrived at. If a standard method was to be arrived at, two considerations came to the front. Firstly, that it must be a representative method; and secondly, that it must come before the members with a certain amount of authority. The methods described in the paper were, so far as he could see, those which had been adopted by the British Aluminium Company for some time past. In so far they were representative, but they were representative of that Company only, and he certainly thought it would have advanced the interest of the paper to the Institute if some reference had been made to methods adopted in other works and in other countries. Seeing that the paper was substantially a statement of the methods of the British Aluminium Company, and that it passed through its hands aluminium samples by the hundred per week, he thought it was a pity that, so far as he remembered, there was no reference to the fact that they were methods which had been used in the standard works of the country. That would have added greatly to the acceptability of the paper in view of the objects set forth in it. He humbly suggested to the authors that if possible something should be done to either clear that up or to make the issue quite distinct. There were one or two points on which, if the members would bear with him, he desired to say a few words. In the first place, there was rather a misleading statement at the bottom of p. 139. It was not intentionally misleading, it was simply a question of juxtaposition. The authors said : "The only data available as to the amount of oxygen in aluminium are contained in an article by Kohn-Abrest, who gives about 2·3 per cent. as the amount in some samples of aluminium powder which he was examining." His own opinion was that it contained more than that.

It of course varied according to the method of preparation. The paper continued : "In other forms of the metal, such as sheets, bars, or castings, which present far less surface, the proportion of oxygen must be very much smaller than this." When one came to examine that statement it was entirely misleading, because it led one to imagine there was some connection between aluminium powder and the surface in regard to the ordinary ingot metal. There was no such connection. Any oxygen which was present in the ingot metal was occluded oxygen, and did not arise from the methods which caused aluminium powder to be a partially oxidised product. There was no doubt whatever that in the process of preparation aluminium powder was superficially oxidised to a greater extent, he was prepared to admit, than the authors had stated. Then he wished to say that already quite a number of methods of analysis had been modified in various details. He did not think he ought to take up time in describing those modifications, as they did not affect the substance, but only the details. There were certain inconveniences which the authors admitted in the way in which the tests were carried out. He (Dr. Bailey) had been able to overcome these inconveniences. There was, for instance, the boiling over ; and in the determination of the silica, for instance, far too much acid was used, certainly far more than was really necessary. Hydrochloric acid, for instance, was a catalytic agent, and quite a minute amount of it was sufficient to bring the aluminium into solution. He did not think he need go into those points, because he thought it would be more generally interesting to the meeting if he referred to the several interesting paragraphs of the paper which were devoted to silica. The authors stated that the silicon, even after the chemical treatment, even after it had been heated in the muffle for a considerable time, remained partially as silicon. He could quite confirm that statement ; in fact, he could go somewhat further. He had found as much as 25 per cent. of that which came out of the aluminium, and which ought to be silica according to the chemistry, to be silicon. He did not know how the authors ascertained how far silicon was present or not, and by what method, but for himself he did it by the evolution of hydrogen and measuring the amount of hydrogen eliminated, and the remarkable thing was that it was evident from the appearance of the precipitate, which was brown or dark coloured. In some cases he ignited the precipitate several times with practically no addition to weight, and yet the statement was made in the text-books that silicon was a substance which was very readily oxidised indeed. He had treated it in the muffle and with an oxidising agent, and yet had failed to get any notable amount of oxidisation ; there still remained a considerable amount of unoxidised silica. He was glad to be able to accentuate a point the previous speaker made in regard to the fact that there still remained with the silica a small amount of alumina. That probably balanced the matter, so that the rough determination was probably after all practically correct ; in fact, he had confirmed that statement by ascertaining that, in ordinary working, although the silicon was not fully oxidised, it was practically made up for in other directions. In connection with that point, he wished the members to remember that

the amount of silica obtained from a gramme of aluminium was, as a rule, from 3 to 5 or 6 milligrammes. Of course some furnaces had a greater amount, depending on the manner in which they were being used, but from 3 to 5 milligrammes was about the correct figure. That was associated in rather a strong solution with about 1000 times its weight of sulphate of alumina. Under those circumstances it was very difficult indeed to wash the alumina completely, and as a matter of fact he had made it the practice to do what the previous speaker very properly recommended. Periodically, as the week's work went on, all the samples of silica after they were weighed were tipped into a bottle. At the end of the week the contents of that bottle were examined, and from 10 to 14 per cent. of alumina was always found there, although the washing was very diligently performed. He thought it would be of general interest if he stated that there were circumstances under which there might be very much more alumina present than that, and they were circumstances under which nine out of ten, if not ninety-nine out of a hundred, analysts worked. He had used for many years, and he still used as showing that it could be used by quite inexperienced chemists, the plan of taking the smallest possible filter to receive a small precipitate. That was not at all novel. But he had gone further, and always insisted that when the solution was poured upon the filter which it was desired to filter it should pass over the edge of the filter, and that when the filter was being washed the wash-water should fill the funnel, although the filter was usually of such a size that it did not occupy more than one-third the height of the funnel. It might be said that one could not expect to keep a filtrate clear in that way. If, however, the filter was perfectly fitted, about which there was no difficulty, and if the funnel especially was properly made, and that could also be secured, he had never known a case where there was any difficulty whatever; thorough washing was obtained. There was a very small amount of filter paper to wash, and it was the filter paper which held the alumina and such-like things. He thought it was very important as a general instruction that all washing of filters should be done in that way. The method was quite easy when once it had been tried, and it stood to reason that the area of the filter was probably not more than one-third of the area which was usually employed. There were one or two statements in the paper with regard to the proportions of silicon, iron, and sodium with which he could not say that he agreed, but perhaps there were others present who were capable of giving better information on that subject than he was.

Mr. T. Vaughan Hughes, Assoc.R.S.M. (Birmingham), agreed with the last speaker's criticism that he hoped the authors would have given details of more recent methods than those described in the paper for the analysis of aluminium. The opinion was expressed in a paper, which was to be read later in the day, that some indication should be given from time to time of the composition of sundry metals and alloys presented to the Institute. In that connection he had taken the trouble to look at some of his results of aluminium in the year 1898, and he desired

to present them simply as a matter of interest, showing how the silicon and the sodium present varied in those years.   They were as follows :—

Silicon per Cent.	Sodium per Cent.
0·70	0·09
0·58	0·17
0·87	0·16
0·68	0·28
0·66	0·14

The methods he adopted were those recommended by Moissan and a few other Continental chemists.   In regard to silicon, he always took the precaution of evaporating with hydrofluoric acid, believing that a more accurate result obtains than by the method of simply weighing a certain precipitate without investigation of its composition.   Even with all the precautions taken, the authors had shown that the silicious precipitate was highly contaminated.   With reference to the remarks of Dr. Bailey, he recommended that gentleman to use, if he had not already used them, very fine paper pulp filters instead of the small paper filter.   He found that when difficulties of washing described occurred, pulp filters were more reliable.   With regard to the evolution method described on p. 144, a check upon the silicon evolved as hydride, it is a curious coincidence that in most of the examples given the percentage of silicon remaining in the washing train was between 5 and 6 per cent. of the total silicon, with the exception of No. 4.   He mentioned this coincidence for what it was worth.   The result might point to some fault in the method of separation, or it might be an indication of a combination which ought to be investigated.

Mr. E. L. RHEAD (Manchester) said it was his intention not to have joined in the discussion on the paper, but after Dr. Bailey's remarks relating to the use of small filter papers, he felt he should be failing in his duty if he allowed the statement to pass that the use of small filter papers in the way described was to be recommended for general purposes. The difficulty that was experienced in getting small filters to attach themselves fairly, even to the most perfect funnels, was, in skilled hands, very considerable, but in the hands of those to whom such analyses were very often given, it was a still greater one.   The trouble of getting precipitates running through the filter was one that he, with a large laboratory experience, could not too strongly lay stress upon.   The use of pulp filters, to which Mr. Vaughan Hughes had already referred, was perhaps to be preferred, because the ease with which the adhesion of the pulp to the edges of the supporting vessel could be obtained was very great.   With regard to the character of the precipitate, he suggested that in dealing with silica it should be treated as he himself had treated it, namely, first of all to moisten the edges of the paper with strong hydrochloric acid in the final washings in order to prevent the retention by that portion of the paper not kept constantly wet with the fluid of a larger amount of alumina than was retained by the lower parts.   He would like to ask the authors whether they had employed

the method of fusing the precipitate with acid sulphate of soda in order to remove the last traces of alumina, re-dissolving, re-filtering, and re-washing the precipitate. That was a method he had found successful in a large number of cases.

Mr. W. MURRAY MORRISON (London) desired to make a few remarks with regard to the typical analyses given by the authors on p. 139. Improvement of the methods used in the manufacture of the metal had made very rapid strides within the last few years. He wished to point out that the metal which the authors designated "extra pure metal" only showed a purity of 99·63 per cent. As a matter of fact it was a comparatively simple matter nowadays to obtain a purity of 99·75 per cent., and even over. The "ordinary English" metal the authors gave as 99·26 per cent. By far the largest quantity of metal turned out in this country at the present time was certainly very much above that figure; it was more like 99·5 or 99·6 per cent. Then the authors said that the amount of sodium which they found in the ordinary English standard metal amounted to 0·04 per cent., and they queried the statement made by Mr. Echevarri as to so low a percentage as 0·003 of sodium being found. In the ordinary grades he (Mr. Morrison) very rarely found more than from 0·008 to 0·01 per cent. of sodium, and it was not at all a rare occurrence to find the sodium as low as that stated by Echevarri, namely, 0·003 per cent. There was another point which was well brought out by the authors to which he should like to allude, namely, the difference between the analysis of other makes of aluminium and the aluminium made in this country. It would be noticed in Table I. that the silicon in each case, with the exception of the metal of English origin, was somewhat higher than the iron. As a matter of fact, in practice the difference was still greater; it was much more like from 0·2 to 0·3 per cent., the silicon in each case predominating. In the English metal the impurities were reversed. There was a difference of from 0·2 to 0·3 per cent., or from 0·1 to 0·3 per cent. as a rule, the silicon in each case being the smaller impurity present. That, of course, had an important bearing, because, as was well known, silicon was much more deleterious as an impurity than iron.

Dr. BAILEY desired to make a few additions to his previous remarks with regard to filters. The matter was of great importance, because it was a general thing which applied to all analyses. He wished to emphasise that there was absolutely no difficulty in carrying out the method he had already described of putting the filter into a funnel and getting it to filter, even although the precipitate was far above it and the liquid. The testers at the British Aluminium Company found no difficulty whatever with the routine analyses, although they were children of fourteen, and were inexperienced in chemistry. A single failure had never occurred in regard to it, and it had been universally adopted by his own students for the last ten or fifteen years. Therefore hundreds of experienced chemists had been turned out who

had used the method, and there was absolutely no difficulty connected with it.

Dr. SELIGMAN, in reply to Mr. Boeddicker's remarks, said the authors clearly pointed out that when extra accuracy was required special precautions must be taken, and they stated that most of their methods were only supposed to give such accuracies as were required in daily work. He scarcely knew what to say in reply to Dr. Bailey's remarks. Dr. Bailey apparently thought that the authors ought to have referred to the British Aluminium Company. Personally he had absolutely no connection of any kind with that Company, although he had been with them for a time, and he could not therefore speak on their behalf, whilst his colleague had been for some years now chemist to the Aluminium Corporation. He did not think it was the case that they were indebted to Dr. Bailey's Company for that paper. They had worked through all the methods given in the paper since severing their connection with the Company. He quite agreed that the action of hydrochloric acid was catalytic, but personally he preferred not to have a standard acid made up, but to vary the proportions as each case demanded. Dr. Bailey said he had found as much as 25 per cent. of silicon in the silicas. He (the author) could go further, and say he had found 28 per cent., but these quantities were only met with in exceptional cases. He also quite agreed that alumina was always present in the precipitates. The figures he had found were not quite as high as Dr. Bailey had given, but he had found 8 per cent. occasionally. Mr. Vaughan Hughes had said he wished more recent methods had been given. The methods given in the paper were those the authors had worked at within the last few months. Although the paper was written six months ago, nothing more recent was available than the methods given in the paper.

Mr. VAUGHAN HUGHES stated that he referred in his remarks to more standard methods, and not more recent methods.

Dr. SELIGMAN, continuing his reply, said that with regard to standards the authors had given their methods with the expressed hope that the members who joined in the discussion would do the same, and that a standard might afterwards be made up. There was no standard at present, otherwise this paper would have no *raison d'être*. He gathered from the many figures which Mr. Vaughan Hughes gave that the amount of sodium present in the metal he referred to was about 0·15 per cent. All he could say in reply to that was that he had not seen a metal quite as bad as that within the last five years, although he quite agreed that formerly such metal was common. Mr. Morrison went to the other extreme, and said that he actually knew of metals containing as little as 0·003 per cent. of sodium. Such a metal had also not come his (Dr. Seligman's) way, and on the same subject he thought Mr. Morrison was perhaps rather sanguine about the purity of the metal. He did not know whether Mr. Morrison would be prepared to supply 100 tons

of metal with 99·75 per cent. of purity. He knew that such metal had been prepared, and there was no scientific reason why metal of 99·99 per cent. purity should not be prepared, only such metal happened not to be a commercial commodity. Mr. Morrison had also stated that the figure of purity of 99·26 for ordinary metal was a little too low for the present day. It was not his experience that the metal with which he dealt nowadays was much better than that. The 99·6 purity which the authors gave as that of the "extra pure" metal, but which Mr. Morrison said was the purity of "ordinary" metal, was taken from a number of analyses which he had recently made of "extra pure metal" supplied as such at enhanced prices by the Company which Mr. Morrison represented.*

COMMUNICATIONS.

Mr. A. V. Hussey (London) wrote that, in connection with the estimation of the total silicon, he did not agree that the amount of hydrochloric acid required for solution was dependent on the purity of the metal. It was true that the rate of solution was dependent on that factor, but every grade of metal might be desolved in a mixture of sulphuric and nitric acids in the proportions given, with various proportions of hydrochloric acid. In that connection, he might say it had been his experience with metal containing fine graphitic silicon that that might be filtered quite readily if solution had taken place slowly, so that the whole of that material was distributed through the dried mass after evaporating to sulphuric acid fumes, instead of adhering to the sides of the beaker. Merely washing down after solution was not effective in that case, owing to the "non-wetting" properties of that particular modification. High silicon metal treated in that way usually gave a residue which granulated easily prior to filtering.

With regard to the iron determination, he (Mr. Hussey) noted that no special mention was made of the purity of the sulphuric acid, whereas the purity of the sodium hydrate was indicated. His experience had been that it was necessary to use acid containing less than 0·002 per cent. of iron in order to obtain accurate results by that method.

As regards the analysis of alloys in connection with the estimation of magnesium, the method used for avoiding the tedious washing did not appear to make any correction for the bulk of the precipitate in

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* With regard to Mr. Morrison's statement in connection with the sodium content of aluminium, the authors wrote subsequently to say that during the last six months they had examined a large number of samples of aluminium from all sources, and had invariably found the true sodium content to vary between 0·039 and 0·016 per cent. That the figure, 0·04 per cent., given in the paper was a little too high for an average they were prepared to admit, and in light of the information that they had obtained since the paper was written, it appeared that 0·03 per cent. would be a safer figure. If Mr. Morrison had obtained such figures as he quoted, they would be interested to know by what method the figures were obtained. The authors certainly held that the onus of proving its existence rested upon Mr. Morrison.

making up to the known volume, of which a measured proportion, free from precipitate, was subsequently taken.

Dr. SELIGMAN wrote, in reply, that with a full report of Dr. Bailey's remarks before him, he saw that he had misunderstood Dr. Bailey's contentions. On the other hand Dr. Bailey seemed not to have understood the remarks contained in the authors' introduction. In their second paragraph the authors categorically stated that they did not attempt to lay down a standard, but only cited their own methods in order to induce other chemists who, like Dr. Bailey, were engaged in analysing aluminium, to do the same. In that way they hoped that the foundations for a standard method might be laid.

As to the oxygen in various forms of aluminium, he (Dr. Seligman) considered Dr. Bailey to be in error. All aluminium which had been exposed to air was covered with a film of oxide, the amount varying, of course, with the amount of surface. Hence in aluminium powder it was far greater than in other forms of the metal, except when the latter had been overheated. In that case a considerable amount of *oxide* was disseminated through the metal. There was no question whatever of occluded oxygen. Dr. Bailey's statement that the amount of oxide in aluminium powder varied with the method of preparation was somewhat cryptic, because there was only one way of preparing aluminium *powder*. Perhaps Dr. Bailey understood the authors to refer to *granulated* aluminium, a totally different material, and one to which Kohn-Abrest's figures did not apply.

He was extremely glad to hear that Dr. Bailey had been able to overcome the difficulties to which attention had been drawn, and he hoped that on some future occasion Dr. Bailey would make known the methods by which this had been accomplished.

He was pleased to learn that Dr. Bailey confirmed his and Mr. Willott's observations on the behaviour of silicon and silica. In several places (*e.g.* page 142, and page 143 footnote) they drew attention to the colour of precipitates containing silicon.

Mr. Morrison was perfectly correct in drawing attention to the relative demerits of silicon and iron, but was wrong in thinking that in the purer grade of foreign metal silicon largely predominated. The following two analyses selected from other recent analyses of French metal illustrate this point :—

				Iron. Per Cent.	*Silicon.* Per Cent.
1	.	.	.	0·28	0·27
2	.	.	.	0·27	0·26

Mr. WILLOTT wrote, in reply, that he thought that Dr. Bailey must be labouring under a delusion, when he stated that the methods described were representative of those used by the British Aluminium Company only. It was not until those methods had been employed in America that they were adopted by the said company, and to the writer's knowledge they were at that time used in France also. In the year 1896 Mr. James Otis Handy read a paper before the American Chemical

Society on Aluminium Analysis, and shortly after this the methods were tried in England, with the result that they—with one exception, viz. the method suggested for the determination of the iron—were adopted by the British Aluminium Company.

The only difference between the methods of determining the total silicon, as practised in America and France, was that whilst the former dissolved the sample in a mixture of hydrochloric, nitric, and sulphuric acids, and worked in $4\frac{1}{2}$ inches diameter porcelain dishes, the latter added the acids separately and worked in small pear-shaped flasks. The English company followed the American method.

For the determination of the iron, the Americans added zinc powder to the silica filtrate and titrated with standard permanganate ; later they reduced with platinised zinc and copper sulphate. The French company allowed their filtrates to drop on to granulated zinc, and after reduction was complete they also titrated with permanganate.

The English company continued to use a gravimetric method, which consisted in dissolving the metal in sodium hydroxide solution, filtering, dissolving the residue in hydrochloric acid, and precipitating with sodium hydrate to remove the last traces of aluminium. Finally the precipitate was redissolved and reprecipitated with ammonia.

Some little time after this Regelsberger's method was adopted, and whilst The British Aluminium Company were responsible for some of the modifications, he did not think it could be said that the methods were representative of any one company.

With reference to the inconvenience of boiling over, that has long since ceased to trouble those frequently engaged in the analysis of aluminium. The difficulty lost its seriousness with the increased purity of the metal. The only reason for making mention of it in the paper was to help those who rarely have to examine this metal, and whilst understanding that the cuttings should be fine, might go to the extreme.

It is very gratifying to see that Dr. Bailey's experience of the graphitic and combined silicon so nearly agreed with that of Dr. Seligman and himself.

He (Mr. Willott) was quite in agreement with Messrs. Boeddicker, E. L. Rhead, and Dr. Bailey that the silicas always contained alumina, and, as Dr. Seligman had said, the amount may occasionally be very high, but with ordinary care this could be reduced to a negligible quantity. Even in ordinary routine work there was no reason why the amount of alumina should not be kept well within 5 per cent. of the total residue obtained, provided that the sampling had been done with reasonable care.

One of the sources of insoluble alumina was the surface coating of oxide, the amount present in the turnings, &c., varying with the thickness of the sample. The surface cuttings should therefore be carefully excluded from the sample.

Dr. Bailey was of the opinion that " far too much acid is used." As the authors suggested adding *only sufficient hydrochloric acid* to dissolve the sample, and as the nitric acid was introduced to oxidise any silicon hydride which might otherwise escape, he took it that Dr. Bailey referred

to the amount of sulphuric acid recommended. That might in part account for the abnormal amount of alumina found in his silicas.

The readiness with which the aluminium salts dissolved after taking down to fuming would depend upon the quantity of sulphuric acid present, and to a certain extent upon the length of time the fuming was continued. If the quantity of acid were unduly reduced the samples would require boiling for a greater length of time, which was objectionable, for two reasons—

   (1) The possibility of some undissolved salt being retained with the silica was increased, thus frequently giving rise to a source of error.

   (2) Some of the silica which was not rendered truly insoluble might be taken up again.

By keeping sufficient sulphuric acid present and adding a few cubic centimetres of hydrochloric acid to the boiling solution a short time before filtering, both sources of error could be considerably diminished.

When the above precautions were taken the amount of alumina retained would, for all practical purposes, not be more than the merest trace.

The suggestion made by Mr. E. L. Rhead as to moistening the edge of the paper with hydrochloric acid was a good one, but he had not found that to be necessary when a little hydrochloric acid had been added to the solution before filtering. Where such analyses have to be conducted in any quantity, the latter course occupied less time and was not so tedious.

With reference to the use of small papers for filtering, as recommended by Dr. Bailey, he was afraid that with some of the very fine silicons nothing but the pulp filters recommended by Mr. Vaughan Hughes would hold back the residue.

With regard to Mr. A. V. Hussey's communication respecting the amount of hydrochloric acid required for the solution of the metal, it was more a question of convenience. In such cases as the analysis of rod and sheet, which were not thick enough conveniently to take turnings or drillings from, it was simpler to take shearings and to add sufficient hydrochloric acid to dissolve the sample in a reasonable time. On the other hand alloys might be met with that would dissolve in the sulphuric and nitric alone without the aid of hydrochloric acid.

A CONTRIBUTION TO THE STUDY OF PHOSPHOR BRONZE

By O. F. HUDSON, A.R.C.S., M.Sc., AND E. F. LAW, A.R.S.M.

ALTHOUGH phosphor bronzes are largely used in the various branches of engineering practice, very little reliable information concerning them was to be found until quite recently, and very little seems to be known of the general constitution and properties of these alloys. Mr. Arnold Philip's paper on
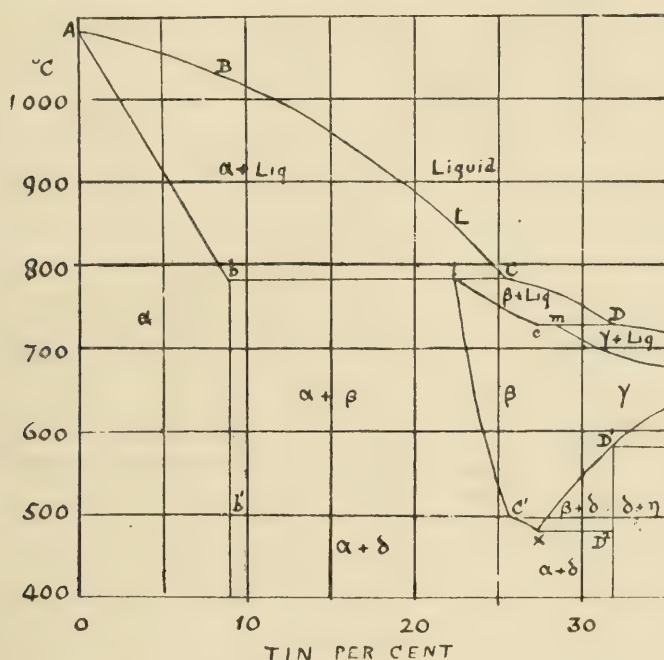
FIG. 1.—Part of Equilibrium Diagram of Copper-tin Alloys.
(Heycock and Neville.)

phosphor bronze, read before this Institute in November 1908, contained a mass of valuable data regarding their chemical composition and mechanical properties, and it is hoped that the results published here will serve to supplement those of Mr. Philip. The object of the research embodied in the present paper is to investigate the relation between the constitution of these alloys and their composition and mechanical

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properties, and while the authors cannot claim as yet to have in any way completely established the constitution of the series, it was thought that results here recorded were of sufficient interest to warrant their publication and might serve to contribute something to our knowledge of the subject.
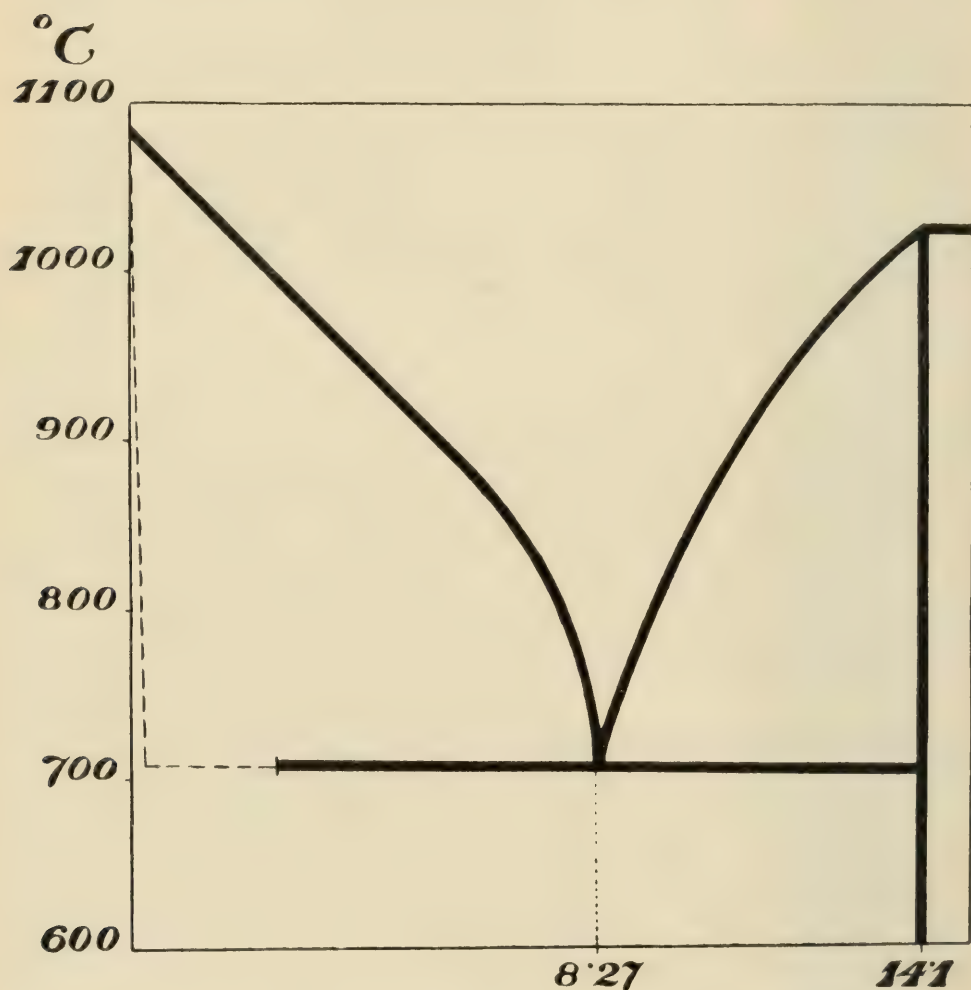
FIG. 2.—Equilibrium Curve of Copper-phosphorus Alloys.   (Heyn and Bauer.)

Before attempting to deal with the triple alloys of copper, tin, and phosphorus, it may be well to refer briefly to the two binary systems, copper-tin investigated by Heycock and Neville ([1]), and copper-phosphorus investigated by Heyn and Bauer ([2]).   To facilitate reference the equilibrium diagrams are here reproduced, Figs. 1 and 2.   Dealing first with the copper-phosphorus system, it will be noted that phosphorus

combines with copper to form a definite phosphide of copper having the formula Cu_3P (14·1 per cent. phosphorus), and that this compound forms with the copper a simple series of alloys having a eutectic consisting of copper and phosphide of copper and a composition 8·2 per cent. phosphorus (M.P. $705°$ C.). In other words, the alloys containing less than 8·2 per cent. phosphorus consist of copper surrounded by the eutectic, while those containing more than this amount of phosphorus consist of phosphide of copper surrounded by eutectic. Plate V., Fig. 1, which represents the eutectic in an alloy containing 11 per cent. phosphorus, shows the characteristic laminated structure, but in the alloys containing low percentages of phosphorus the constituents of the eutectic seem to coalesce with the production of a much coarser structure, showing large rounded masses of phosphide of copper. It is also worthy of note that copper when solid is capable of dissolving more phosphorus than is indicated on the diagram of Heyn and Bauer. Thus a phosphor copper containing 0·9 per cent. of phosphorus has an almost homogeneous structure after annealing for two hours at $690°$ C., or four hours at $640°$ C. In any case, in alloys with less than 1 per cent. phosphorus, the characteristic eutectic structure is not seen unless the alloy has been very rapidly cooled, and under ordinary conditions of casting the phosphide of copper is present in comparatively large masses as a separate constituent.

The copper-tin series is much more complex, but in the alloys which are here dealt with, *i.e.* those at the copper end, there are only two constituents that must be recognised, viz. the solid solution of tin in copper (a) containing, in the ordinary cast alloys, up to 8 per cent. tin,* and in those alloys containing more than 8 per cent. tin the constituent known as δ, which has usually been regarded as the compound Cu_4Sn. For the purpose of this paper, and to avoid complication, it will be called Cu_4Sn; it has a characteristic blue-grey colour of a much lighter shade than the phosphide of copper. The two compounds Cu_4Sn and Cu_3P form a binary

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* The amount of tin that may be found in solid solution in copper in the a constituent varies with the rate of cooling ; in an alloy that has been cooled with extreme slowness, or has been thoroughly annealed, copper is able to hold as much as 13 per cent. of tin in solid solution at the ordinary temperature. [3]

eutectic having a composition 72 per cent. copper, 25 per cent. tin, and 3 per cent. phosphorus, and together with the tin-copper solid solution α give rise to a ternary eutectic having the following composition—copper, 81 per cent. ; tin, 14·2 per cent.; phosphorus, 4·8 per cent. As already stated, the alloys of copper and tin containing less than 8 per cent. of tin consist of a single solid solution. On adding phosphorus to these alloys the phosphide eutectic separates out as in the copper-phosphorus series, but the eutectic never shows the banded structure, and is more broken up and more evenly distributed throughout the mass of the alloy than is the case in the phosphor coppers (see Plate V. Fig. 2, and Plate VI. Fig. 3). It must again be noted that, as in the case of the alloys consisting only of copper and phosphorus, the copper in the phosphor bronzes is capable of dissolving an appreciable amount of phosphorus if the alloy is cooled with extreme slowness or is annealed. The phosphorus, however, when present in minute quantities, is seen as phosphide of copper in a cast phosphor bronze that has been cooled at the ordinary rate.

When more than 4·5 per cent. tin is present another constituent makes its appearance in the slowly cooled alloys, and this constituent, which is evidently Cu_4Sn, forms with the Cu_3P and the solid solution a ternary · eutectic. The addition of small quantities of phosphorus thus lowers the solubility of tin in copper from 8 to 4·5 per cent. Further additions of phosphorus separate out as phosphide but do not decrease to any great extent the solubility of the tin. Here again the rate of cooling has a marked effect on the structure, and causes the ternary eutectic to be present in alloys containing much less than the above amount of tin. In alloys containing more than 4·5 per cent. of tin the addition of phosphorus gives rise to the formation of the ternary eutectic, and any excess of phosphorus over and above that required to form this ternary eutectic separates out as massive phosphide (or the binary eutectic, Cu—Cu_3P, in an exceedingly coarse condition). In the case of alloys containing higher percentages of tin more of the ternary eutectic is formed until the alloy containing 81 per cent. copper, 14·2 per cent. tin, and 4·8 per cent. phosphorus is reached, which

α. Copper with tin and phosphorus in solution.
P. Phosphide of copper, or binary eutectic of
    copper and phosphide of copper.
T. Ternary eutectic.
δ. Cu₄Sn.
B. Binary eutectic of Cu₄Sn and Cu₃P.
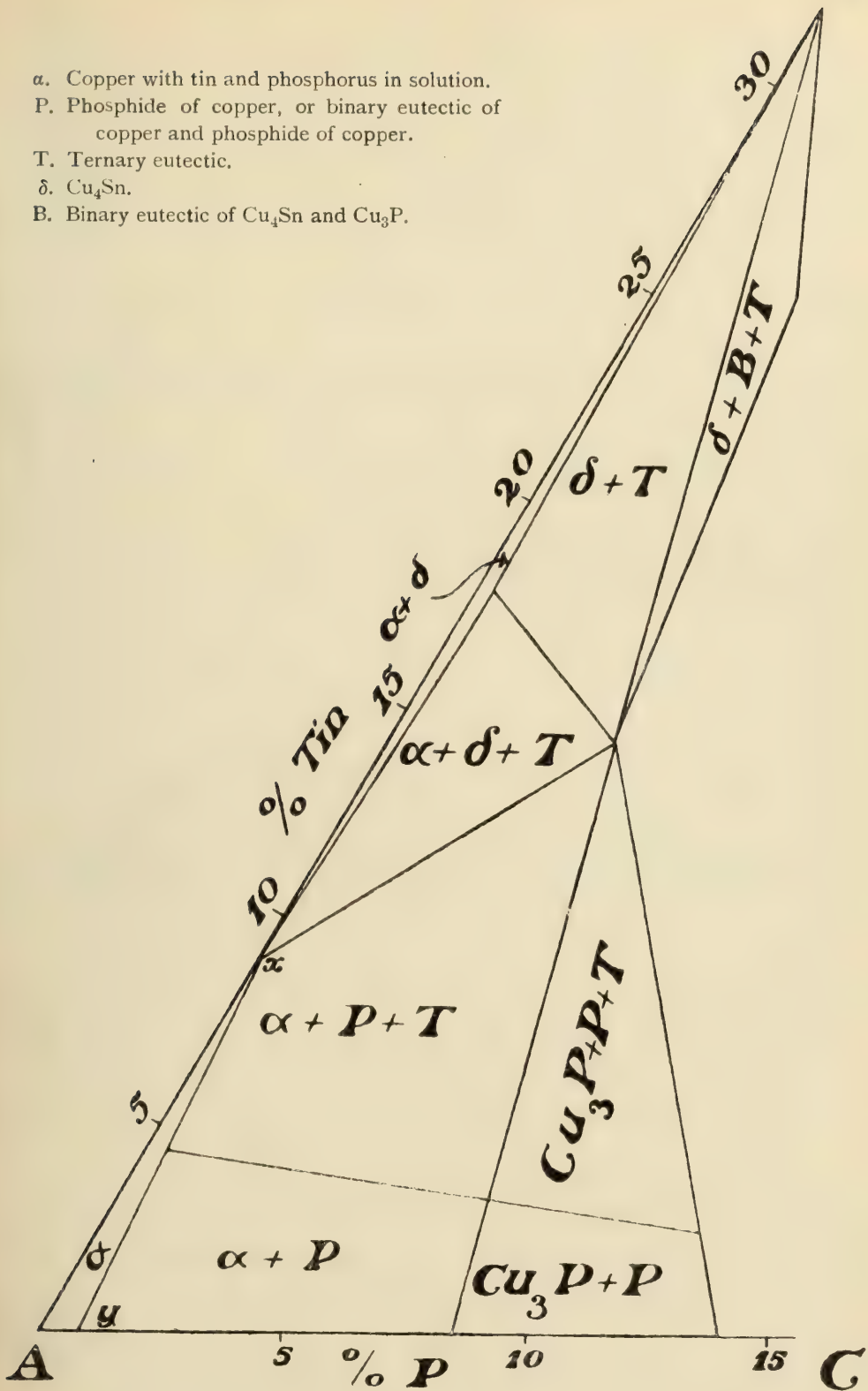
FIG. 3.—Constitutional Diagram of slowly cooled Phosphor Bronzes.

is the pure ternary eutectic melting at 620° C. The accompanying diagram, Fig. 3, illustrates the constitution at the ordinary temperature of the very slowly cooled alloys which are dealt with here. This constitutional diagram will be modified somewhat by rate of cooling. Thus quick cooling such as obtains under ordinary casting conditions
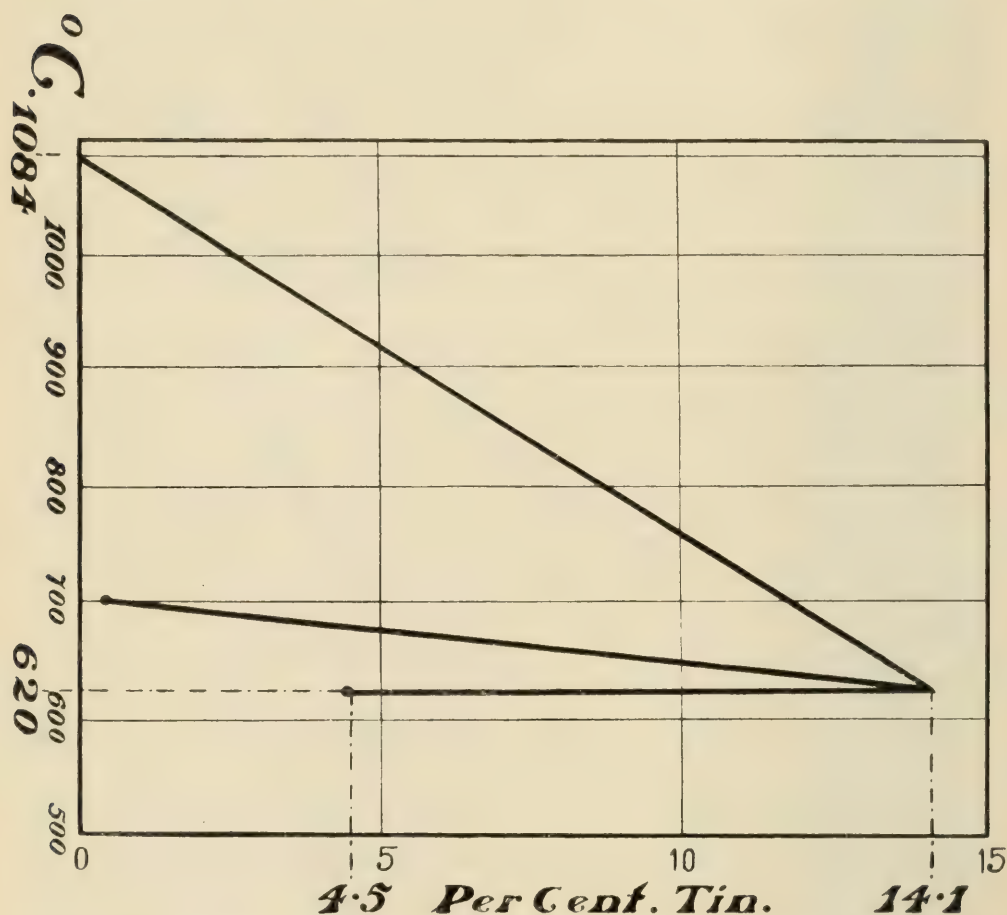
FIG. 4.—Freezing-point Diagram of Copper-tin-phosphorus Alloys, containing 4·8 per cent. Phosphorus.

causes the line *xy* to be displaced to the left, in fact it usually coincides with AB. For example, a casting containing 5 per cent. tin and 0·05 per cent. phosphorus may show a small amount of the copper phosphide.

The cooling curves of the alloys containing less than about 5 per cent. of tin, therefore, show only two breaks, the higher being the freezing-point of the copper (or, to be more exact,

copper containing tin and phosphorus in solution) and the lower the freezing-point of the phosphide eutectic. On the other hand, the alloys containing more than about 5 per cent. tin show three breaks, the highest being the freezing-point of the copper, the second, between 700° and 625° C., the freezing-point of the phosphide eutectic, and the lowest,
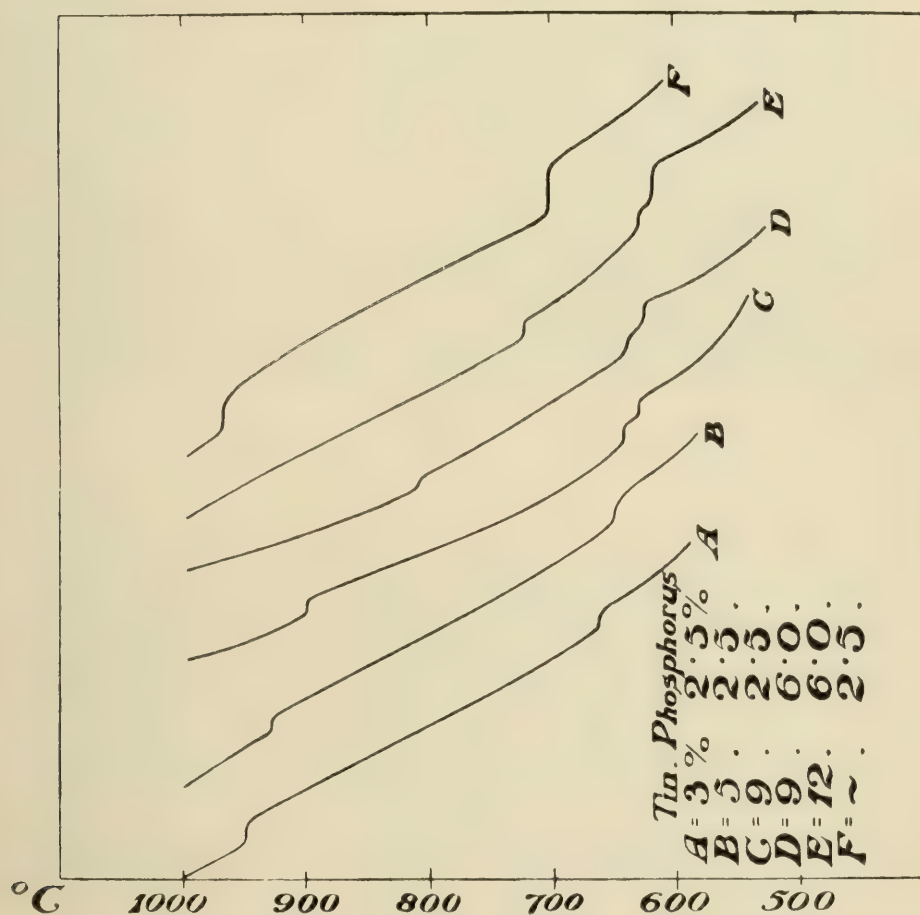
Fig. 5.—Typical Cooling Curves of Copper-tin-phosphorus Alloys.

at 620° C., the freezing-point of the triple eutectic. The two classes of cooling curves may be summarised in the freezing-point diagram, Fig. 4, for a percentage of phosphorus of about 4·8, and some typical cooling curves of copper-tin-phosphorus alloys are given in Fig. 5.

The microstructures of the alloys dealt with are illustrated by Plates V. to XIV., Figs. 1 to 20.

PRACTICAL CONSIDERATIONS.

The significance of these results is apparent when we consider the relation between the constitution and the widely varying mechanical properties of the alloys which are known collectively as phosphor bronzes. It may be recalled that the commercial phosphor bronzes may be classified according to their mechanical properties into two groups: (1) the malleable phosphor bronzes, which are used for various purposes in the form of plate, sheet, rod and wire; and (2) the cast phosphor bronzes, which are used in cases where a metal is required to resist wear and reduce friction, such as bearings, gear-wheels, worm-gearing, slide-valves, &c. The bronzes in which phosphorus is added in small quantities and merely plays the part of a deoxidiser need not be considered here, as they are outside the scope of the present paper. Bronzes containing lead will be referred to later.

The malleable phosphor bronzes are those in which the quantities of both tin and phosphorus are relatively small; that is to say, in quantities insufficient to form the ternary eutectic. In actual practice the quantities present will of course depend to some extent on the degree of malleability and ductility required, but the upper limits may be taken as 6 per cent. of tin and 0·3 per cent. of phosphorus. In his paper on the phosphor bronzes Mr. Philip draws attention to an alloy possessing approximately this composition (6·5 per cent. tin and 0·32 per cent. phosphorus), which was used for braiding electric cables, and which, he says, two or three makers declared could not be manufactured.

Now from a study of the constitution of these alloys it will be seen that their malleability is due to two causes. In the first place, the solubility of phosphide of copper, due to the annealing which this class of alloy necessarily undergoes, gives rise to a homogeneous product consisting of a single solid solution. Secondly, the presence of tin plays a part in maintaining the malleability of the alloy, which is of considerable interest from a metallurgical point of view. As has already been pointed out, even if phosphorus is present in

PLATE V
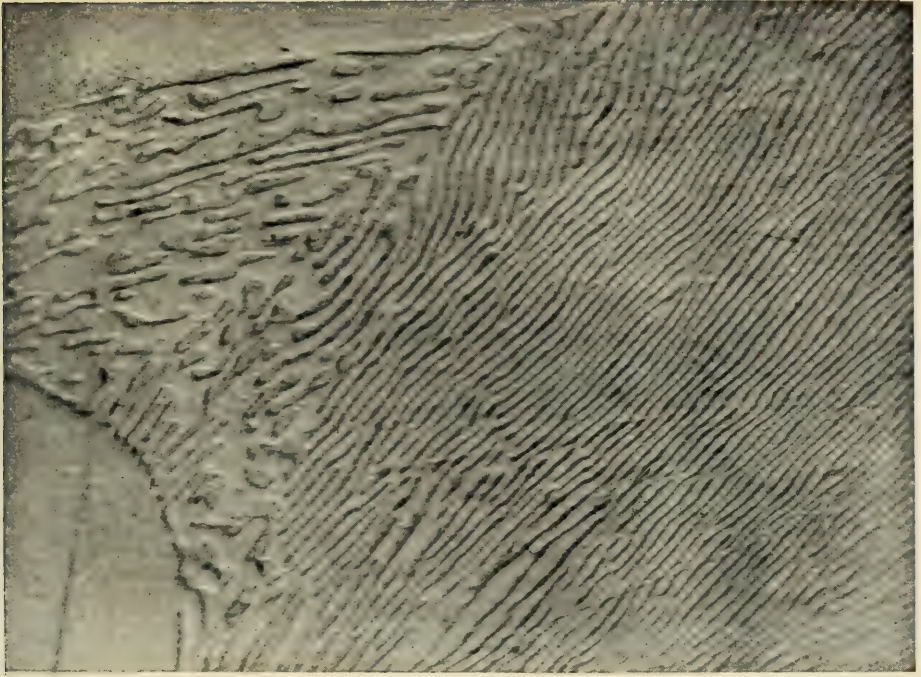
FIG. 1.—Eutectic of Copper and Cu₃P in a Phosphor-copper containing 11 per cent. of Phosphorus. Magnified 1000 diameters.
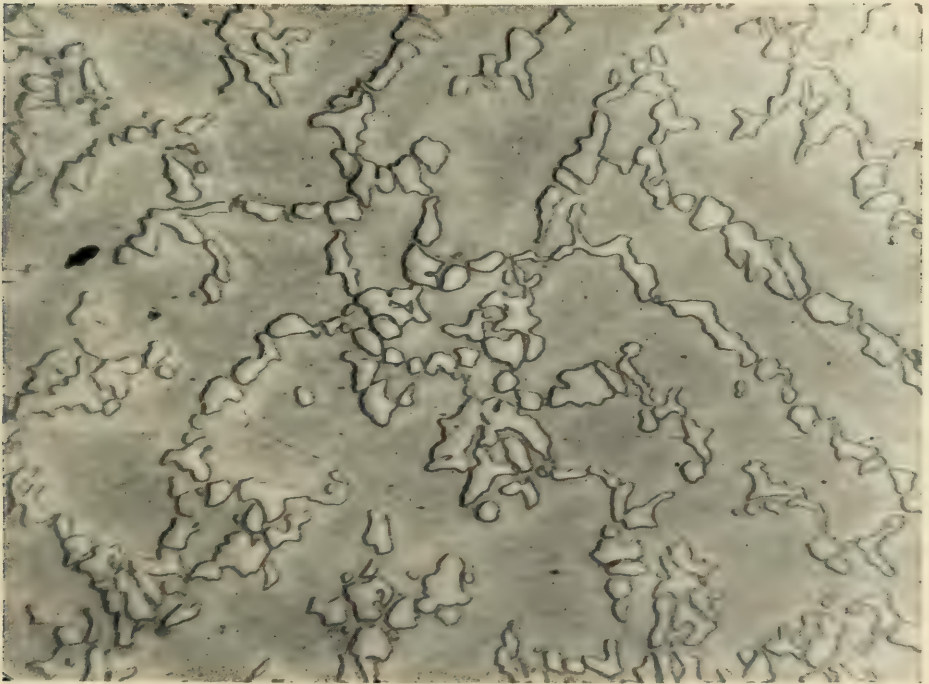
FIG. 2.—Phosphide in an Alloy containing 1·8 per cent. Phosphorus and 1·2 per cent. Tin, showing absence of Eutectic Structure. Magnified 100 diameters.

PLATE VI

FIG. 3.—Phosphide in an Alloy containing 1·8 per cent. Phosphorus and 1·2 per cent. Tin, showing absence of Eutectic Structure. Magnified 1000 diameters.
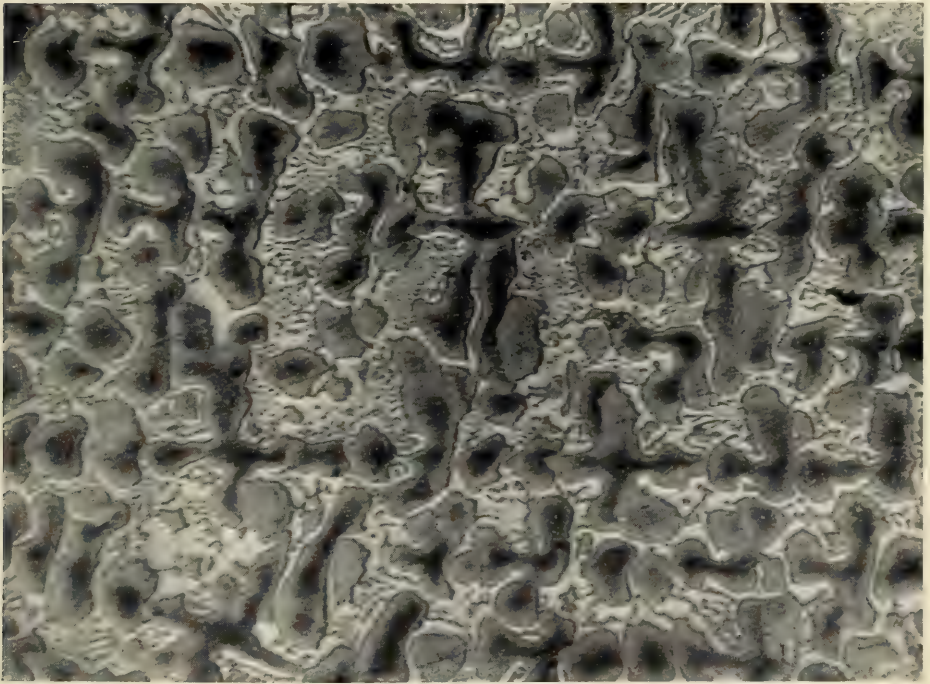
FIG. 4.—Phosphor-copper containing 5 per cent. Phosphorus. Magnified 100 diameters.

PLATE VII

Fig. 5.—Phosphor-copper containing 5 per cent. Phosphorus.
Magnified 1000 diameters.
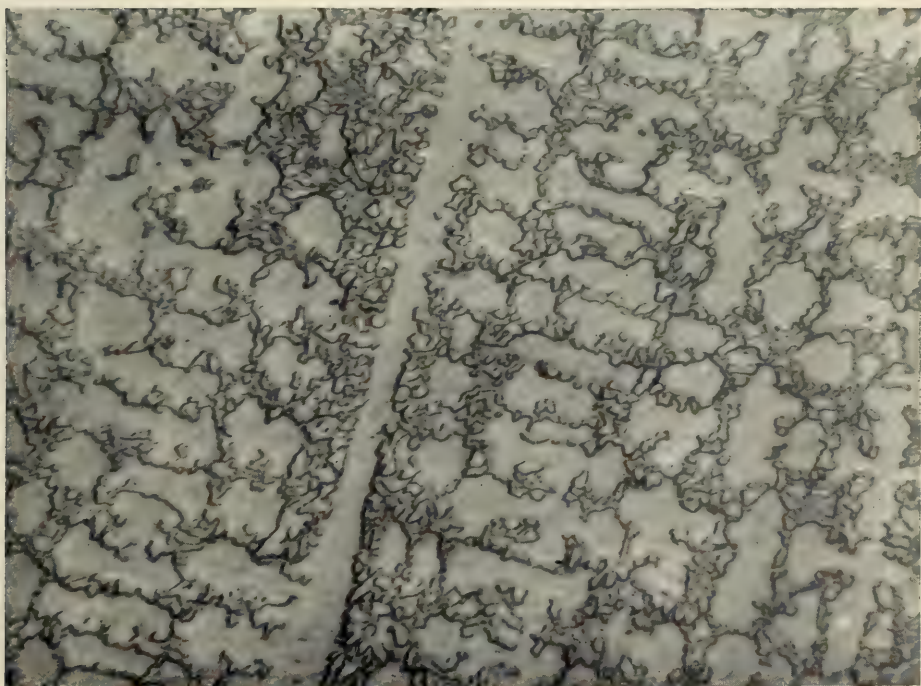
Fig. 6.—Phosphor-copper containing 5 per cent. Phosphorus and 4 per cent. Tin.
Magnified 100 diameters.

PLATE VIII
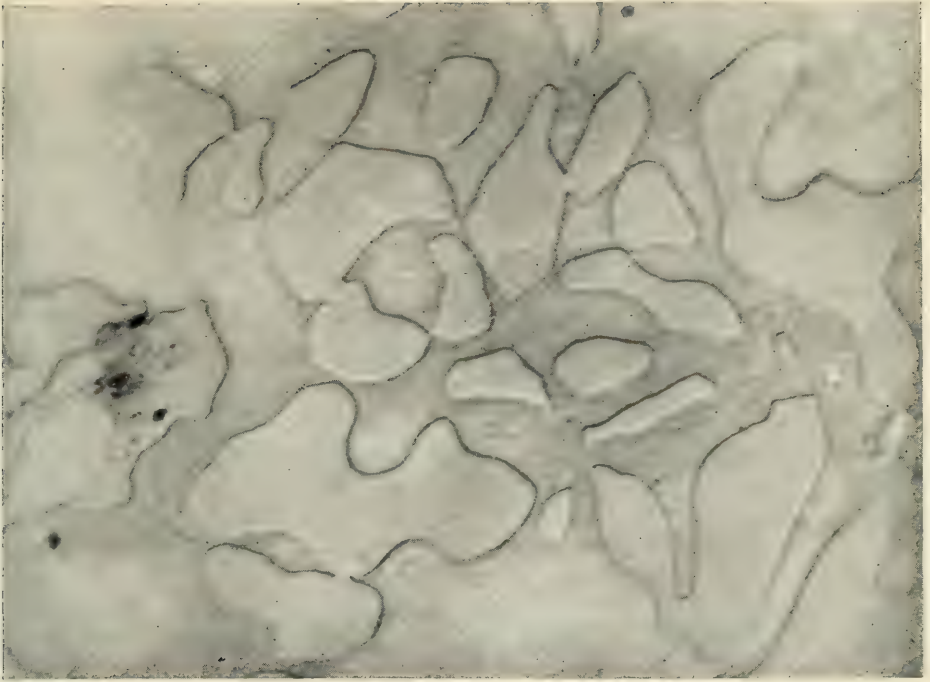
FIG. 7.—Phosphor-copper containing 5 per cent. Phosphorus and 4 per cent. Tin.
Magnified 1000 diameters.
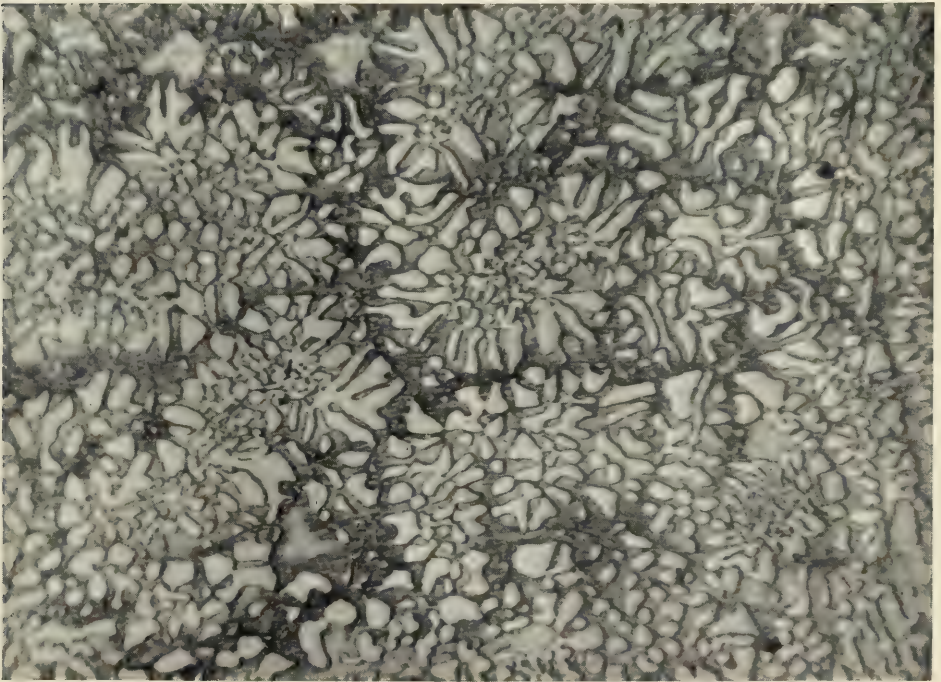
FIG. 8.—Bronze containing 6·7 per cent. Phosphorus and 5 per cent. Tin, nearly
free from Triple Eutectic.   Magnified 100 diameters.

PLATE IX
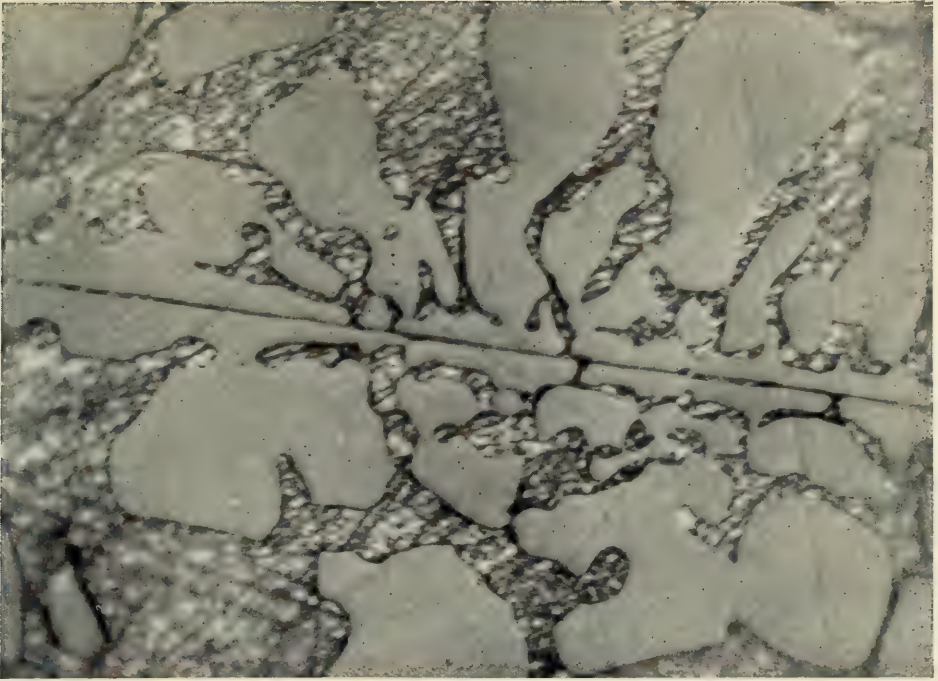
FIG. 9.—Bronze containing 6·7 per cent. of Phosphorus and 5 per cent. Tin, nearly free from Triple Eutectic.   Magnified 1000 diameters.
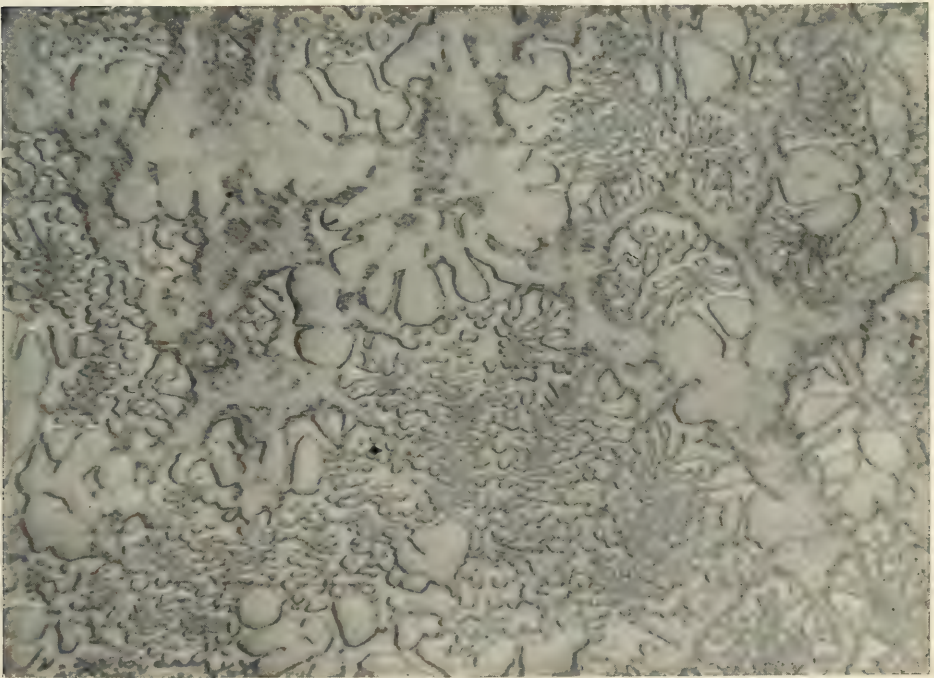
FIG. 10.—Bronze containing 6·6 per cent. Phosphorus and 9 per cent. Tin, containing much Triple Eutectic.   Magnified 100 diameters.

PLATE X
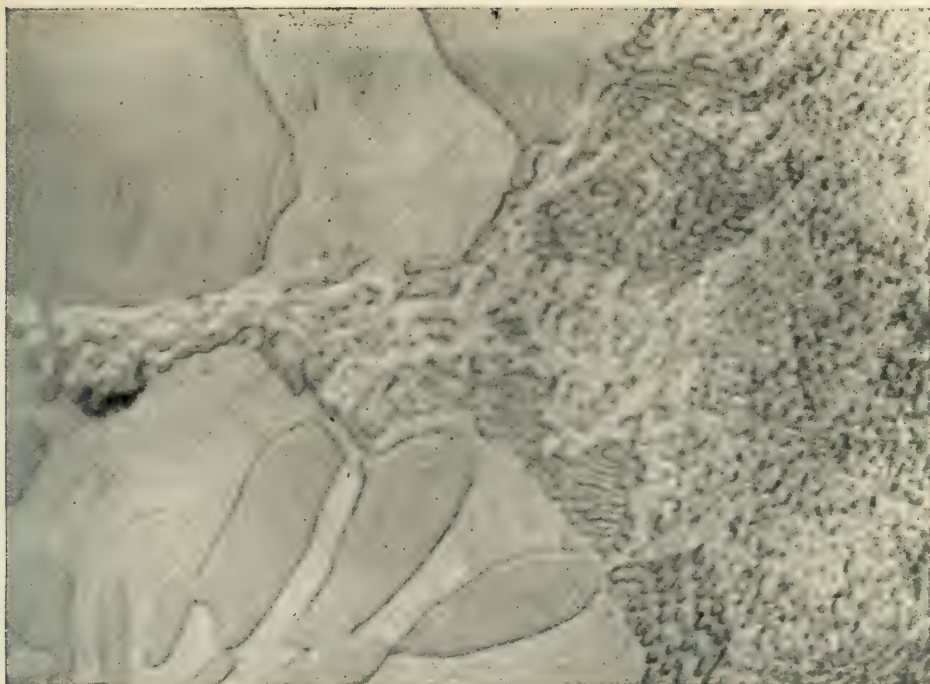
FIG. 11.—Bronze containing 6·6 per cent. Phosphorus and 9 per cent. Tin, containing much Triple Eutectic. Magnified 1000 diameters.
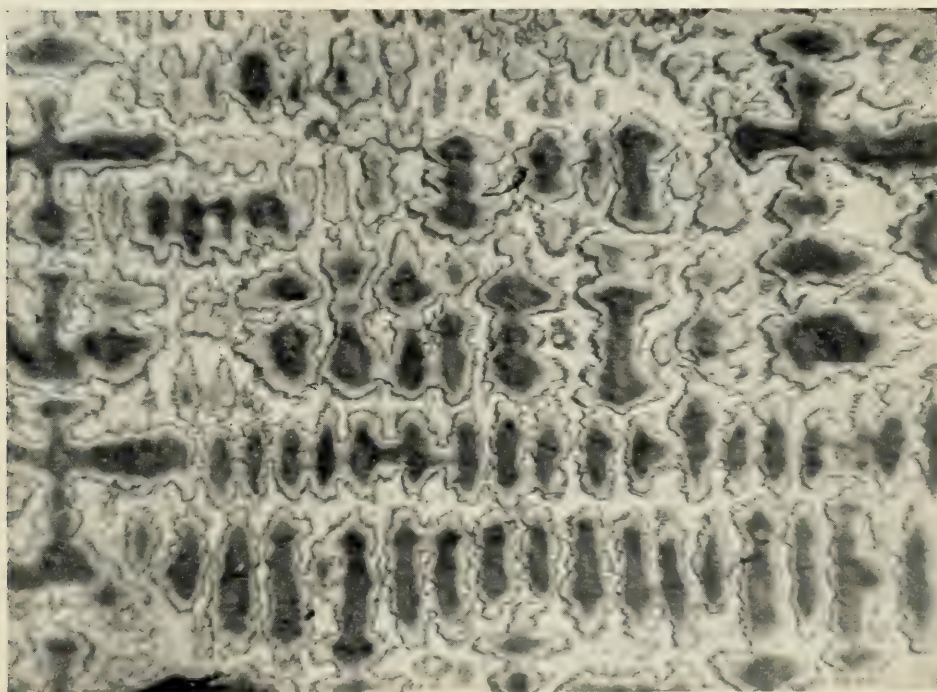
FIG. 12.—Bronze containing 2·0 per cent. Phosphorus and 12 per cent. Tin, consisting entirely of α and Triple Eutectic. Magnified 100 diameters.

PLATE XI
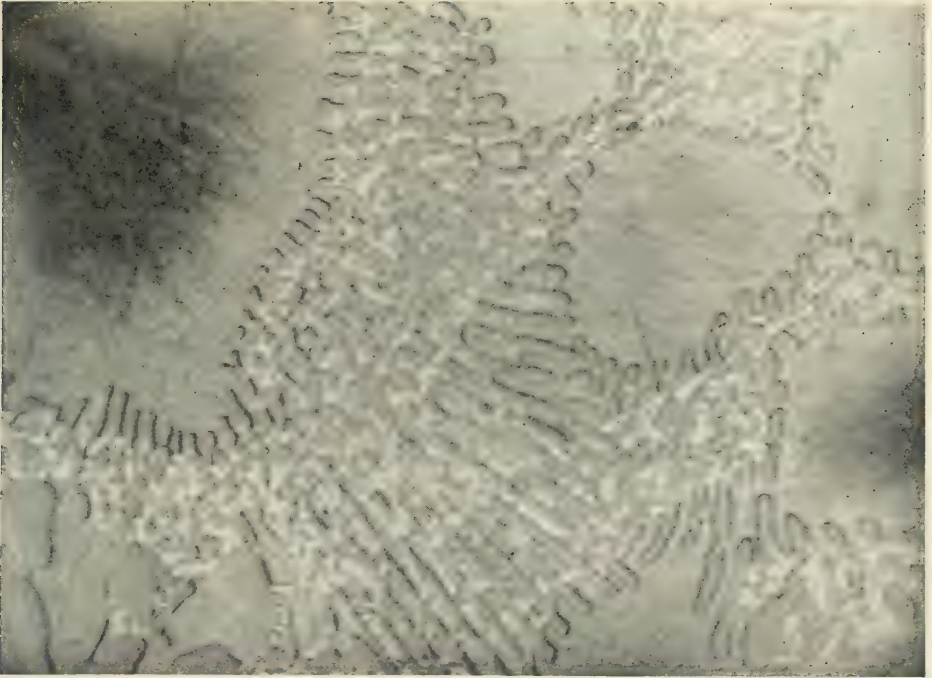
Fig. 13.—Bronze containing 2·0 per cent. Phosphorus and 12 per cent. Tin, consisting entirely of α and Triple Eutectic.   Magnified 1000 diameters.
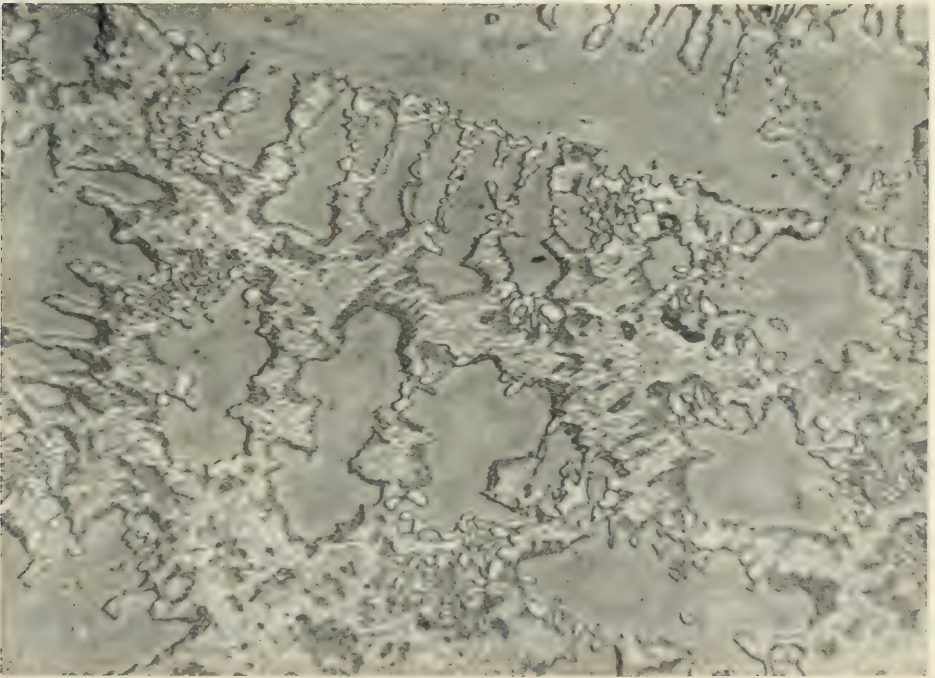
Fig. 14.—Bronze containing 3·1 per cent. Phosphorus and 12 per cent. Tin, showing Triple Eutectic and Massive Phosphide.   Magnified 100 diameters.

PLATE XII
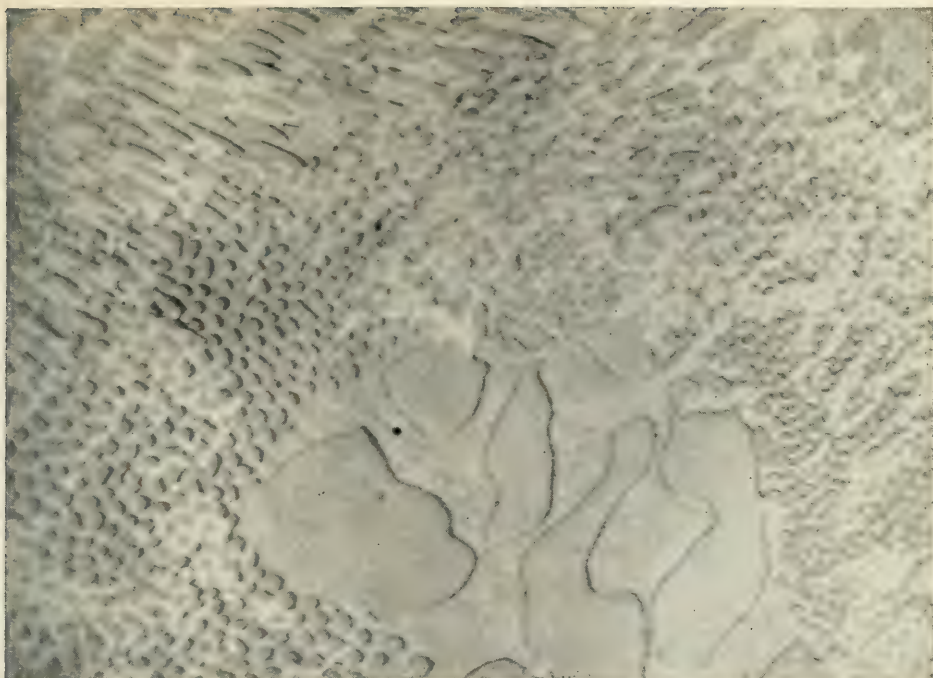
FIG. 15.—Bronze containing 3·1 per cent. Phosphorus and 12 per cent. Tin, showing Triple Eutectic and Massive Phosphide.   Magnified 1000 diameters.
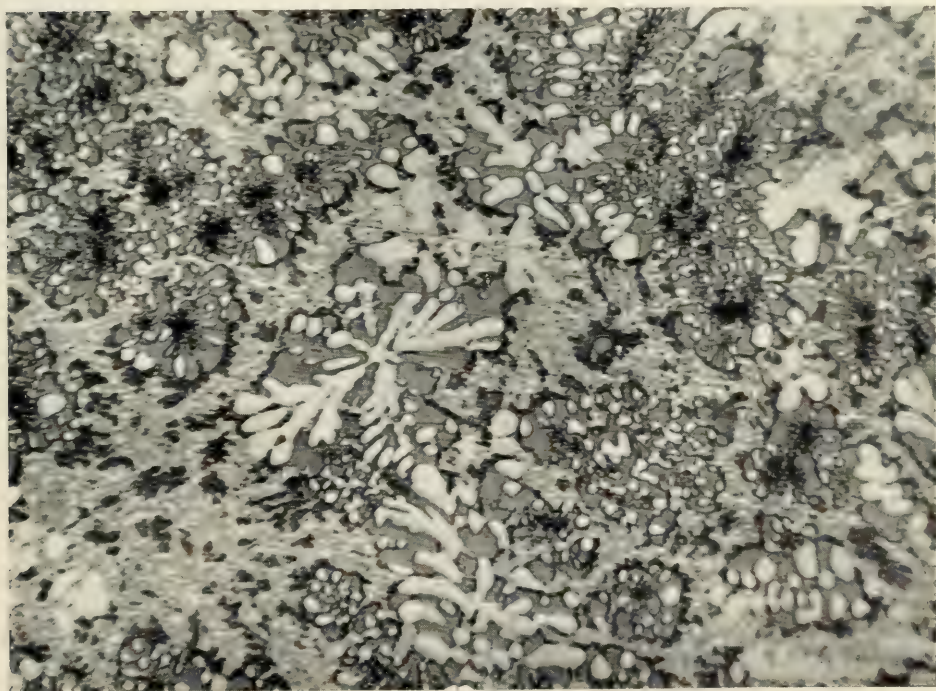
FIG. 16.—Bronze containing 5·4 per cent. Phosphorus and 12 per cent. Tin, consisting largely of Triple Eutectic with Free Phosphide and Copper.   Magnified 100 diameters.

PLATE XIII
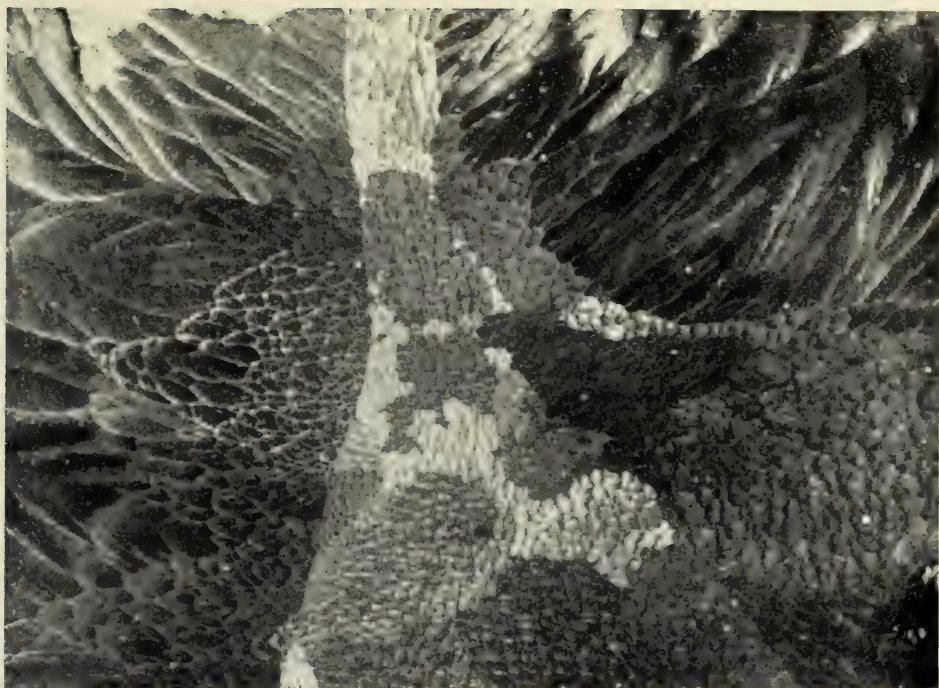
FIG. 17.—Triple Eutectic.   Magnified 10 diameters (oblique).
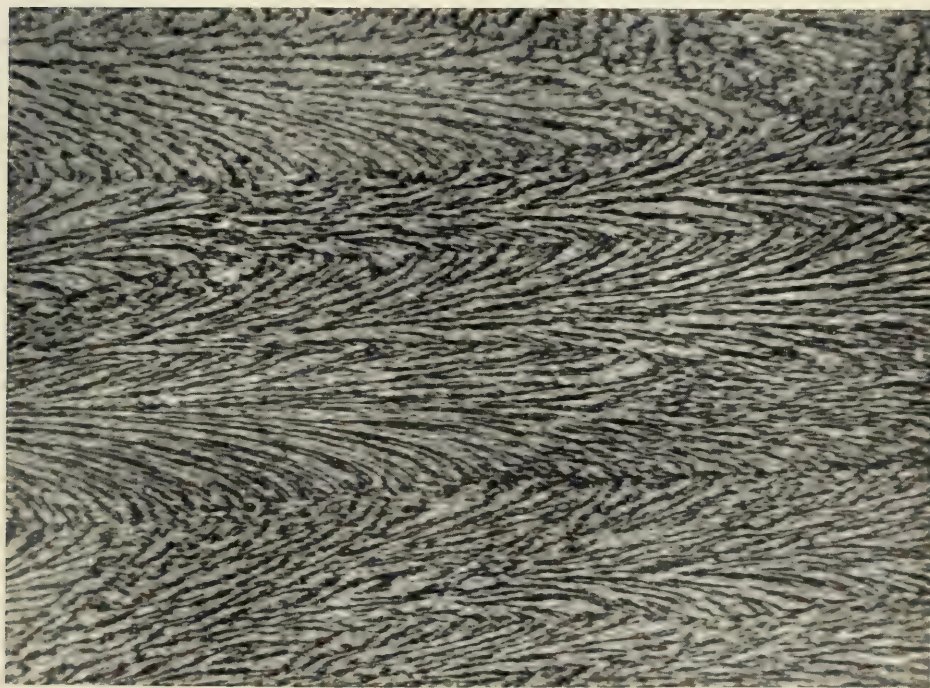
FIG. 18.—Triple Eutectic.   Magnified 100 diameters.

PLATE XIV
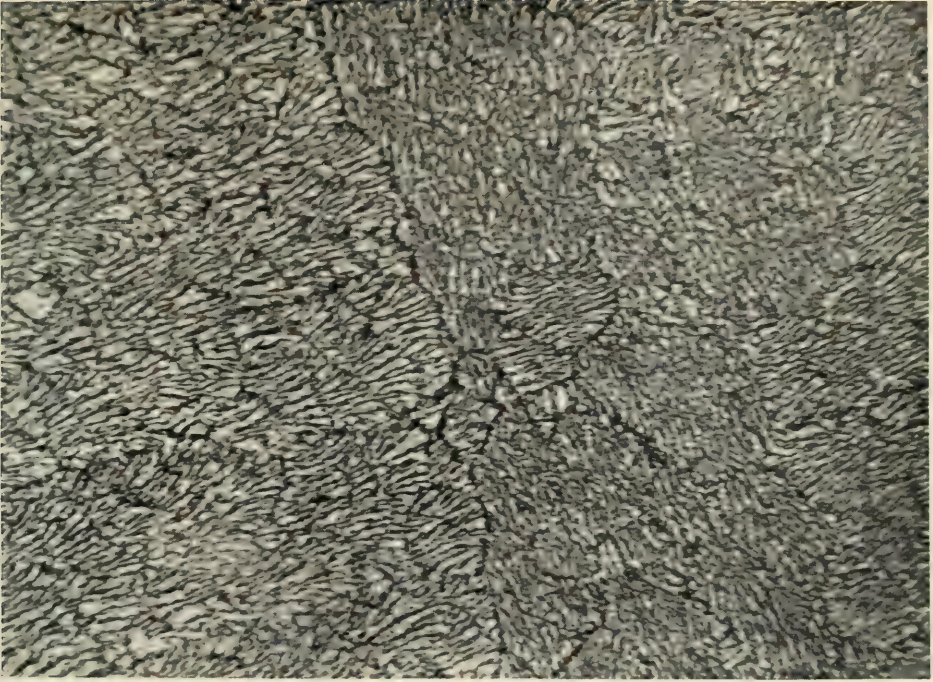
FIG. 19.—Triple Eutectic, section in Different Plane. Magnified 100 diameters.
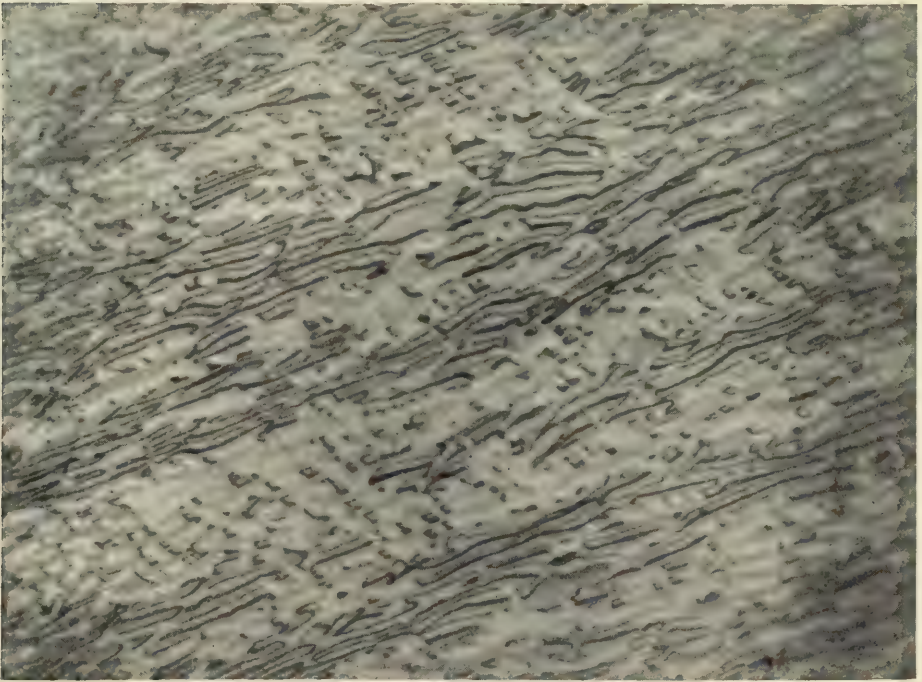
FIG. 20.—Triple Eutectic. Magnified 1000 diameters.

sufficient quantity to form free phosphide of copper the presence of tin hinders the formation of the phosphide eutectic, and instead of separating out between the crystals of the copper, or in large masses, the phosphide occurs in small, more or less rounded particles, which are evenly distributed throughout the mass of the alloy. A structure of this type gives the maximum degree of malleability possible in an alloy composed of more than one constituent. Plates VI., VII., and VIII., Figs. 4, 5, 6, 7, representing two alloys both containing 5 per cent. of phosphorus, one containing no tin and the other 4 per cent. of tin, will illustrate the change in structure due to the tin. The influence of tin on the mechanical properties is shown by the following tests. Both samples were turned down from cast bars which had had no work put upon them.

Analysis.			Breaking Load. Tons per Square Inch.	Yield Point. Tons per Square Inch.	Elongation per Cent. on 2 Inches.
Cu.	Sn.	P.			
99·52	0·00	0·48	3·8	3·0	3·5
94·65	5·00	0·35	14·5	7·1	17·5

As regards the cast phosphor bronzes in which the properties aimed at are low coefficient of friction, resistance to wear, and strength rather than malleability, here again the composition naturally depends within certain limits on the use to which the alloy is to be put, but the upper limits may be taken as 12 per cent. of tin and 1·5 per cent. of phosphorus. These alloys possess the essential structure of a good bearing metal, viz. particles of a hard constituent (the ternary eutectic which is often accompanied by free phosphide) embedded in a softer matrix. The ternary eutectic is intensely hard and moreover is not easily crushed, so that the softer matrix is soon worn down, leaving the hard eutectic standing in relief, with the result that the load is carried by these hard particles, thus giving the maximum resistance to wear with a minimum of surface exposed to friction.

A few words may be added with regard to the phosphor bronzes containing lead which are frequently used as bearing

metals. The constitution of these alloys is exactly the same as the other phosphor bronzes, except that the lead, which does not alloy with the copper, separates out in the form of minute globules evenly distributed throughout the mass. In these alloys the lead probably plays the part of a lubricant while at the same time it increases the plasticity.

NOTE ON THE MICROSCOPICAL EXAMINATION OF PHOSPHOR BRONZES.

The microscopical examination of the phosphor bronzes presents no serious difficulties. The samples are most rapidly polished by hand, the final polish being carried out with Globe polish. As in the case of the majority of copper alloys, the best etching agent is a 10 per cent. aqueous solution of ammonium persulphate. This reagent possesses the property of dissolving certain metals, among them copper, without any evolution of gas and without the formation of any surface film, so that no rubbing is necessary but merely immersion in the solution. The only precaution to be observed is that the surface of the specimen should be free from any trace of grease, this being easily secured by the application of a solution of potash or soda immediately before immersion in the persulphate. Ammonium persulphate has been in constant use by one of us for the last seven years on all classes of copper alloys, and has proved more satisfactory than any other etching agent.

Owing to the similarity in colour between the copper-tin and copper-phosphorus compounds it is exceedingly difficult to obtain a truthful photographic rendering of these alloys in monochrome. With suitable screens it can be accomplished, but the most satisfactory results are obtained when the photographs are taken on colour plates.

NOTE ON ANALYTICAL METHODS.

The analysis of phosphor bronze presents some little difficulty owing to the fact that on dissolving the alloy in nitric acid the phosphorus is found with the tin in the insoluble residue, or in the case of alloys rich in phosphorus

partly in the tin oxide residue and partly in the copper solution. The tin* may be separated from the phosphorus in the insoluble residue by fusing with potassium cyanide, digesting the fused mass with hot water, filtering off the metallic tin, destroying the cyanide in the filtrate, which contains the phosphorus as phosphate, by boiling with hydrochloric acid and estimating the phosphorus as phospho-molybdate. This method, although giving reliable results, is long and somewhat tedious, and the following method, which was found to be reasonably accurate and much quicker, was adopted in analysing most of the later alloys :—

The phosphor bronze (0·5 to 2 grammes depending on percentage of phosphorus) is weighed out into a 10-oz. beaker, 20 cubic centimetres of hydrochloric acid is added, and 10 cubic centimetres of a cold saturated solution of potassium chlorate. Boil until all the alloy is dissolved, more potassium chlorate being added in the form of crystals if necessary, and all chlorine is driven off. The solution is then diluted with about an equal bulk of water, and pure granulated zinc added until all the copper and tin are precipitated and no further deposit is observed on a piece of clean zinc foil placed in the liquid. The deposited metals are then filtered off, washed, transferred to a beaker, dissolved in nitric acid, and the tin determined as SnO_2. The phosphorus is determined in the filtrate as phospho-molybdate in the usual way.

REFERENCES.

1. *Philosophical Transactions*, 1903 (A), vol. ccii. pp. 1–69.
2. *Metallurgie*, 1907, p. 242.
3. Shepherd and Blough, *Journal of Physical Chemistry*, 1906, vol. x. p. 630.

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* For this and other methods of analysing phosphor bronze reference may be made to works on analysis such as Brearley and Ibbotson's "Analysis of Steelworks Materials."

DISCUSSION.

Mr. A. PHILIP, B.Sc. (Portsmouth), congratulated the authors on the extraordinarily fine micrographic prints which they had obtained of the phosphor-copper-tin alloys. The relief effect of the banded structure of the copper and copper phosphide was extremely beautiful. In fact, the whole of the prints were of great merit.

The chief point to which he wished to call attention in this paper, was the difficulty he had found in grasping precisely what justification existed for speaking of a triple eutectic in copper-tin-phosphorus alloys and for defining its composition.

A material such as phosphor copper could only contain either pure copper or phosphorus copper compounds ; phosphorus itself was clearly absent. In micrographic sections of phosphor coppers his own observations, and also those of Professor Huntington and Dr. Desch, if he understood them correctly, had shown both cuprous phosphide (Cu_3P) and copper to be present. That the dove-coloured constituent was actually Cu_3P had been demonstrated by micrographic measurements and other tests. The authors, however, referred to a phosphorus copper compound containing 8·2 per cent. of phosphorus. This compound he understood could, and did, exist in the liquid form as a eutectic, but at the moment of solidification it appeared to him to change into cuprous phosphide and copper, the solid alloy showing only the banded structure of these two materials, much as in pearlite the bands consisted of alternate layers of cementite and ferrite. Did he understand the authors to claim that the copper phosphorus compound containing 8·2 per cent. of phosphorus actually existed in phosphor coppers when in the solid state ? That is to say, did solid phosphor coppers consist of admixtures of only cuprous phosphide and copper (in which latter perhaps a very small amount of phosphorus was dissolved), or was there also a third solid constituent, a copper phosphorus compound present containing 8·2 per cent. of phosphorus ?

Passing to solid copper-tin-phosphorus alloys, it appeared to him clear that certainly these also contained pure cuprous phosphide, and also, he thought, the practically pure tin-copper alloy. The fact that the cuprous phosphide was present as such in these alloys he believed was admitted by the authors, and his own micrographic and other tests had also, he considered, shown that this was the case, whilst the very interesting observation made by Mr. G. E. Buttenshaw, as recorded on pp. 196 to 197 of the *Journal of the Institute of Metals*, No. 1, 1909, vol. i., showed that pure copper phosphide would liquate out from a copper-tin-phosphorus alloy on solidifying, and was a very direct proof that this material actually existed in a phosphor bronze. As a phosphor bronze containing definite proportions of copper, tin, and phosphorus was the same material whether prepared from phosphor tin or from phosphor copper, it was evident that melted phosphor tin in contact with melted copper formed cuprous phosphide and metallic tin. But what was the evidence for the existence of the solid copper phosphorus tin compound

which the authors, as he understood, considered to be present? The very beautiful colour photographs Mr. Law had shown certainly gave some support to this view, and he thought that a certain weight of evidence ought to be rightly allowed to the colourings produced by either etching or heat-tinting on such micro-sections, but at the same time it appeared to him that these indications were not conclusive; such heat-tintings were presumably due to films of oxides, and the thickness of these films must depend upon the temperature to which the various constituents were raised, and the time during which they were exposed to the air; the conductivities of the materials present (assuming them to consist of cuprous phosphide and a copper-tin alloy) probably differed, and these different conductivities of the constituents might cause portions of the one material surrounded by portions of the other to heat and cool at different rates to portions having a different space relationship, and hence perhaps cause portions of the same chemical composition to take markedly different tints. He did not wish to be understood to claim that in a solid copper-phosphorus-tin alloy a triple compound did not exist; he merely wished to state that as far as he had been able to follow the authors' paper, the chief, if not the only, evidence at present available appeared to him to be that of the colour photographs. The authors might accuse him of not having thoroughly digested their paper, and he feared this might be true, but he hoped that in their reply they would collect and point out the cumulative evidence for the existence of this triple compound in the solid state concerning which he was now in doubt. Clerk-Maxwell had imagined a demon capable of sorting the high velocity from the low velocity particles of a gas, and he thought it would be very convenient if such a being could be provided for the use of metallographists, a demon who would dig out the various constituents of a micrometallic section, and collect them in sufficient quantities for a chemical analysis: one would then be able to feel more confidence in relying upon the real existence of the solid constituents of complex metallic alloys.

Dr. W. Rosenhain (Teddington) said he had read the paper with much interest, and particularly admired the photo-micrographs, but, like Mr. Philip, although on different grounds, he felt that the evidence as stated in the paper was insufficient fully to support the conclusions set out by the authors. He did not wish to say that the authors were not correct in their conclusions, nor even that they had not yet done the necessary experiments to prove them, but they had not described these experiments in the paper. That was the chief criticism he offered. He had said and written the same thing on previous occasions, and he wished to repeat it as emphatically as he could, that it was most important that the Institute should have all the data upon which the calculations were based. The conclusions were after all to a considerable extent fallible. The best of workers might not be right in their conclusions, but the facts, if they were obtained by careful observers, were incontrovertible and permanent, and were most valuable in future research. He therefore asked that more facts should be published if they were available.

The paper as it stood with the evidence it contained, quite apart from any weight which might attach to it as an authoritative statement, was a careful first approximation to the constitution of the phosphor bronzes, and gave at any rate an insight into the kind of thing which one might expect to find in the phosphor bronzes. But he thought there was a great deal of difficulty, as far as a reader of the paper could judge without intimate knowledge of what the authors had done, in accepting some of their interpretations. For instance, the authors spoke about the complication caused in the microstructure by the formation of the δ constituent of the copper-tin series at about 500° C., whereas the triple eutectic, if he remembered rightly, solidified some 100° higher than that. What he would like to see, and what he thought it was necessary should be seen if the structure of the triple eutectic were to be accepted, was a section of a specimen which had been quenched from a temperature above that of the formation of the δ body, so that the interference of the δ formation had been eliminated ; and so far he could not find that in the paper. Also, before one could accept the eutectic as being really a triple eutectic—and thus far he agreed with Mr. Philip—one would have to see something of the liquidus of the system. There were difficulties attending the liquidus of a system containing a volatile element like phosphorus, but if the experimental investigation of such a system were undertaken, those difficulties must be faced if conclusive results were to be presented. Without that the results were of interest as a first approximation, but he did not think they should be regarded as anything more than that. With regard to the series of possible compounds which Mr. Philip had mentioned, he thought reference to the phase rule would simplify the whole matter very considerably, and if Mr. Philip would look at the question in that light, he thought that gentleman would feel rather less inclined to look for five or six compounds simultaneously existing in an alloy of that kind. He also wished to say that it had been his fate to investigate a ternary system free from the complication of volatility, but favoured with other complications, and all he could say was that without the liquidus the whole thing became exceedingly hazy and vague. He desired to ask the authors to frankly state their own opinion of the degree of accuracy to be attached to the very pretty diagram of the phases which was given in the paper. The remarks he had made were not intended in any way to deprecate the value of the paper, but he thought they were considerations which must be kept in mind when such a paper was discussed and before practical people were asked to rely upon it.

Mr. H. Spence Thomas (Cardiff) said that he had been one of the users of phosphor bronze for some twenty-two years, and he had, therefore, read the paper with much interest. The user naturally expected considerable improvement when using phosphor bronze bearings as compared with ordinary brass bearings. Possibly collaboration between makers of phosphor bronze and scientists would permit the unfortunate users to obtain some guarantee of longer life for their brasses or phosphor bronze bearings than they were getting. Referring solely to hot mill

rolls, his firm had had some bearings running under their hot mills sometimes for one month and sometimes for fifteen months, a huge difference considering they were used under exactly similar conditions. The failure could, in his opinion, only be due to the incorrect mixture or heat treatment of the alloys. It was simply terrible to contemplate the losses entailed by a bearing giving out in one month compared with a possible actual existence of fifteen months, and he was in hopes that from the publication of the paper, together with the President's remarks at the opening session with regard to the game being played with all the cards on the table, the producers of phosphor bronzes would be able to give to the users of these alloys bearings which would last longer than fifteen months. He much appreciated the very beautiful photo-micrographs which Mr. Law had shown on the screen, and he hoped that their display might aid the production of phosphor bronze bearings which would be of real utility to users.

Professor T. TURNER, M.Sc., Honorary Treasurer, desired to say a few words with regard to the usefulness of the paper, and the indebtedness of the Institute to the authors for the amount of information they had laid before the members. The ordinary person who used metals spoke of phosphor bronze as though it were one material. Those, however, who were familiar with the working of phosphor bronze knew that there were almost as great differences in the properties of various kinds of phosphor bronze as there were in the varieties of cast iron, wrought iron, and steel, and that very considerable differences in results might be obtained, in the first place, by variation of the constituents ; and, in the second place, particularly by the heat treatment ; and that one kind of phosphor bronze which was specially suited, for instance, for the drawing of wire was entirely unsuited for the production of bearings. He thought the members were indebted to the authors for information which would enable them to know, when the knowledge was properly applied, how to treat certain alloys which nowadays presented difficulties. Many of those present might know that there were specifications required in connection with phosphor bronze wire at the present time, and that some makers at all events had considerable difficulty in complying with those specifications, and with drawing the wire so as to produce at the same time a clean surface and to prevent any clogging during the process of wire drawing. He believed there were some manufacturers who would be very pleased to pay a reasonable sum of money for information as to exactly how those particular varieties of phosphor bronze should be, or could be, best treated. It was, in his opinion, to the scientific aspect that those persons who wished for such information must look if they were to understand what took place during the processes of annealing and of heat treatment in various other ways. They might have doubts as to whether or not the triple eutectic actually existed of the composition mentioned by the authors. On that point he ventured to say nothing ; he was quite sure the authors would be able to take care of themselves. But that there was a constituent which could be recognised, which had a practical effect, and which disappeared or reappeared according to the heat treatment,

were facts which, from a practical point of view, must have a very important application. He had been interested, too, in the method of analysis given in the paper; it was new to him when Mr. Hudson directed his attention to it not very long ago. Probably the members were aware that, to the ordinary chemist, the analysis of a phosphor bronze was not a very easy estimation. Those who were familiar with phosphor bronze might smile at the difficulties which others experienced, but he would like to give an illustration. A senior student came to him a short time ago, and wishing to know something of what he had done before, he (Professor Turner) asked him a few questions, and the student in reply told him that he had analysed phosphor bronze. On inquiring as to the method adopted, the student mentioned a method which was described in some of the well-known text-books; he asked the student how he liked the method, and received the reply that it was a very nice one, the only difficulty being that he did not find any phosphorus at the end of it! It would be found that there were certain methods which had just that one disadvantage, that they did not give a correct result in reference to the phosphorus. The method given in the paper was extremely simple, and he was told by Mr. Hudson the result of his experience that it was quite satisfactory, and if it were for nothing else than that the members were greatly indebted to the authors for their paper.

Mr. T. Vaughan Hughes, Assoc.R.S.M. (Birmingham), said that the previous speakers had anticipated the remarks he intended to make. He entirely agreed with the observations on the heat conductivity of the films. He considered the paper an excellent one. He wished to emphasise one point: if those compounds existed to which Mr. Philip had referred, and also the compounds mentioned in the paper, could they not be synthetically produced, their actual properties determined, and mixtures of them made in order to ascertain whether the particular combinations which were referred to, and from which the diagrams were produced, could be artificially built up?

Mr. Law, in reply to Mr. Philip's remarks, said that, as Dr. Rosenhain had pointed out, it was known that there was only a possibility of a certain number of compounds existing in any given series, and, as a result of accumulated evidence, the authors came to their conclusions, which were rather too long to go into at the present moment. With regard to Dr Rosenhain's remarks, he thought the authors might be justified in quoting the remark made on p. 162, that "The authors cannot claim as yet to have in any way completely established the constitution of the series." They did not lay claim, he thought, to too much, and moreover there was no finality about such things. If, in research work, we waited until it was absolutely certain there was nothing more to be done, he was afraid that nothing would be published at all. In regard to the publication of all facts, if they published every experiment they had made, and the results obtained, he was afraid the Secretary would not publish them in the Journal. It was necessary to make a judicious

selection of the results, because that was the only possible thing which could be done under the circumstances. With regard to the value of the diagram given on p. 165, he thought Dr. Rosenhain would rather like it, and that was largely the authors' reason for putting it in. Mr. Spence Thomas had made some very valuable comments. He was glad that gentleman spoke, because the Institute wanted the opinions of practical men, who had used phosphor bronze for bearings and other purposes. He understood from Mr. Thomas that in his hot mill bearings phosphor bronze had not been altogether satisfactory. He thought it was possible the explanation was that the triple eutectic, which had such a low melting-point—620°—might not stand a very high temperature, and as the whole bearing depended on that triple eutectic, if anything went wrong with it at a high temperature that would account for the trouble. He would like to ask Mr. Thomas if he had tried a phosphor bronze bearing for his cold mills, and if so, whether they had been more successful than in the hot mills. He thought that information would be very useful to the members.

Mr. HUDSON, in reply, said there were only two or three points to which he wished to refer. The diagram given was not, of course, an equilibrium diagram. It was simply a diagram to illustrate what was the constitution of the alloys at the ordinary temperature that had been very slowly cooled. The question had also been raised as to the value or efficacy of heat-tinting the alloys. He thought that had already been well established by the work of Stead, Osmond, and others, and it was also well to remember that the slides which had been shown by Mr. Law were those of the heat-tinted specimens, because by that method they could be best illustrated on a lantern slide. To those, however, who in any way objected to the method of heat-tinting, he would say that all the photo micrographs given in the paper were obtained from specimens that had been etched by the method described in the paper, and had not been heat-tinted.

Mr. SPENCE THOMAS, in reply to Mr. Law's question, said that he had used phosphor bronze for the cold mill bearings, and sometimes they had been better and sometimes worse. He had been unable to get anything definite from their use.

Mr. C. F. GAYWOOD (Birmingham) thought the unsatisfactory nature of the phosphor bronze to which Mr. Thomas had referred was due to its composition. There was probably too much lead in the bearings.

Mr. SPENCE THOMAS replied that he bought the bearings as phosphor bronze ; he did not know what the makers gave him.

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COMMUNICATIONS.

Mr. G. D. Bengough, M.A. (Liverpool), wrote that he thought Messrs. Hudson and Law's paper an admirable contribution to the study of phosphor bronze. Very few of the members had sufficient time at their disposal to enable them to present finished and final studies of questions connected with triple alloys. Such studies always involved an enormous amount of work. In default, shorter papers of the type sent in by Messrs. Hudson and Law were very valuable, and few workers could approach the wonderful technique of their photo-micrographs.

One of the great merits of papers of that type was that in addition to adding something to the knowledge of ascertained facts they showed what gaps still existed in our information, and so stimulated further work. For instance, on p. 162 the authors showed that the constitution of copper-phosphorus alloys, which had been studied by Heyn and Bauer, and was usually regarded as settled by their work, needed considerable revision for alloys brought strictly to equilibrium.

There were one or two points upon which the writer would like a little additional information. He would like to know how the composition of the binary eutectic between Cu_4Sn and Cu_3P was determined. Also, to what extent did the authors consider that phosphorus, or Cu_3P, was soluble in copper containing tin for alloys, brought strictly to equilibrium. Lastly, would the authors state definitely at what rate the alloys which were used in the experiments carried out for the determination of the diagram on p. 165 were cooled. He thought that information would add very greatly to the value of the diagram, especially since it did not represent alloys brought to equilibrium.

Under the heading "Practical Considerations" the authors stated that malleable phosphor bronzes owed their peculiar properties to the fact that the annealing which they underwent rendered them homogeneous. It would be of interest if the authors would state the conditions of time and temperature necessary to produce homogeneity. Such a statement would have a direct practical importance, since if those conditions were not fulfilled a brittle alloy would result.

On pp. 168 and 169 the co-relation between the type of structure and the mechanical properties was highly important. It would seem that the authors were correct in assigning the improved properties of the tube mentioned second in the table of mechanical tests to the type of structure and not *directly* to the presence of tin, which, though it might account for a considerable increase in the breaking load, would certainly not account for the great increase in the elongation, except indirectly. It would be very interesting to see whether the authors' statement that a structure of the type referred to in the paper gave in general, and not only in that particular case, the maximum amount of malleability possible in an alloy composed of more than one constituent. The writer was inclined to the view that it would hold in several other cases with which he was familiar.

Mr. C. A. EDWARDS (Manchester) wrote that the fact admitted by the authors that they had not completely established the constitution of the series of alloys should not detract from the value of the paper as presented.

Investigations of that character on such widely used alloys as the phosphor bronzes were much needed, and would no doubt form the bases of any future research on the treatment and properties of the alloys.

Considering the alloy referred to as the ternary eutectic, and accepting the term eutectic in its strict sense—*i.e.* that the mixture had a lower freezing-point than any of its three components, or, in other words, the addition of any of the components to the eutectic alloy raised the temperature at which the mixture began to solidify—then the writer was of the opinion that no ternary eutectic could be formed in the system, copper—Cu_4Sn—Cu_3P. In the first place, it was a theorem of physical chemistry that no ternary eutectic could be formed unless each of the three binaries of which the system was composed contained a eutectic.* On referring to Fig. 1, it would be seen that there was no eutectic in the system copper—Cu_4Sn. In such a case it was possible to have a ternary non-variant point corresponding to the point c in Fig. 1, but it would not be a eutectic. That an alloy containing 81·0 of copper, 14·2 of tin, and 4·8 of phosphorus showed three constituents when viewed under the microscope could be explained by considering that two constituents only were deposited from the liquid—viz. Cu_3P and β of the copper-tin series, and that the α is a secondary constituent formed from β along a line similar to $1c$ in Fig. 1.

It was probable that the $\alpha + \delta$ area (Fig. 3) did not represent the alloys of that composition in a stable condition, since the points x and B indicated that neither α, with about 9·0 per cent. of tin, nor δ were capable of holding phosphorus in solid solution, but the area implied that when those two constituents were together a certain amount of phosphorus was dissolved. That was somewhat strange, but no doubt due to differences in the rate of cooling.

Though the two questions here raised had little or no practical significance, they were of theoretical interest and worthy of consideration.

Mr. W. B. PARKER (Rugby) wrote that Messrs. Hudson and Law's paper was a good introduction to a series of alloys presenting unusual difficulties. He suggested the desirability of adding the equilibrium curve for the phosphor-tin alloys containing up to, say, 15 per cent. phosphorus, because it was probably the alloy most used in manufacturing the triple alloys, and would be necessary for subsequent work on these lines. The paper supplied valuable information concerning the "composition and constitution" of the alloys, but only imperfectly illustrated the relation between their "mechanical properties and constitution." Only two mechanical tests were given, and neither a description of the appearance of their fractured surfaces nor their photo-micrographs were

* R. Sahmen and A. von Vegesach, *Zeitschrift für Physikalische Chemie*, vol. lix. p. 280.

given. The writer desired to know whether these could be supplied? No information was given showing how the alloys studied were made up, and there were needed the analyses of the raw materials used—the latter was *most* important. For instance, phosphor-tin sometimes contained lead—even up to 2 per cent. The lead might have been introduced unintentionally, for instance, by using tin-foil for wrapping the phosphorus in when making up the phosphor-tin. Tin-foil was seldom pure tin ; it sometimes contained as much as 88 per cent. of lead. The distribution of the phosphorus amongst the contending affinities was very interesting, but to clinch the points discovered there was required a chemical method on the lines of Mr. Stead's analytical estimation of the *condition* of phosphorus in cast irons. It would be interesting to know whether the authors had noted differences in the chemical behaviour of the phosphorus in the " Alpha " solid solution compared with that in the copper phosphide and eutectics. For example, did the relative amounts of phosphorus found in the tin oxide precipitate and the copper filtrate obtained in the ordinary nitric acid method of analysis bear any relation to the structural conditions of the phosphorus in the alloy? To illustrate, he (Mr. Parker) quoted the only case he had thus investigated. The sample was the bottom portion of a "runner," about 6 square inch area, cut off a dry sand casting made with very pure electrolytic copper, and weighing 300 lbs. The manufacturing conditions were favourable to *moderately slow continuous cooling*. The composition of the runner was determined, firstly, by the " 1·2 specific gravity nitric acid method," treating the tin oxide by fusion with caustic alkali, &c., to recover any phosphorus. The results were :—

	Per Cent.
Copper	95·62
Tin	4·32
Phosphorus (total)	0·057

A second determination, by the potassium chlorate and hydrochloric acid method, gave :—

	Per Cent.
Phosphorus (total)	0·054

A duplicate of the nitric acid method in which the phosphorus left in the tin precipitate and that passing into the nitric acid filtrate were separately determined gave :—

	Per Cent.
Phosphorus (in tin oxide)	0·055
,, (in acid filtrate)	Trace.
Total	0·055

A duplicate by the chlorate method was evaporated, and gently fused in a platinum dish to ensure all free chlorine was eliminated, which gave :—

	Per Cent.
Phosphorus (total)	0·054

Finally, a variation of the hydrochloric acid method, using pure bromine instead of potassium chlorate, was used. This variation was much to be

preferred, because bromine was easier to " boil off " than chlorine, did not introduce any alkaline base, and was more likely to oxidise volatile hydrides of phosphorus, if liberated, and would thus give more accurate results for total phosphorus. This method gave :—

	Per Cent.
Phosphorus (total)	0·058

The mean of all five determinations was 0·0556 per cent. of phosphorus. A microscopic examination of the same piece of metal showed the Alpha constituent with well defined segregations of phosphide of copper, some small, some larger. Judging roughly, they would account for all the phosphorus found by analysis. The larger segregations of phosphide had a duplex structure. The tin and phosphorus were so low that it was unlikely the duplex segregations were ternary eutectic. That indicated that practically the whole of the phosphorus was present as phosphide of copper, and that when it occurred in that form it was left almost entirely with the tin oxide produced by gently heating with 1·2 specific gravity nitric acid. The rate at which 300 lbs. of alloy cast in dry sand " under ordinary casting conditions " would cool, could not be said to be " quick cooling." On that point he disagreed with the authors' statement on p. 166. It should be described as " *moderately slow*, continuous cooling," and he believed that accounted for the duplex structure of the eutectic, also that only 0·002 per cent. of phosphorus was retained in the " Alpha " solid solution. Both structures of the eutectic were normal to such conditions. Possibly the authors had confused the product normal to a process of slow but *continuous* cooling, compared with the product of a prolonged annealing, or soaking, at a relatively high temperature *followed* by a slow cooling.* The observations recorded on pp. 163, 164, and 169 respecting phosphide of copper and its eutectics in ordinarily cooled and chilled castings proved definitely that when phosphor-tin was utilised for manufacturing the triple alloys it would be decomposed, the phosphorus having a greater affinity for copper than for tin. Therefore, theoretically, it would not matter whether phosphor-tin or phosphor-copper was used. However, it did matter in practice, as the " furnaces-losses " of phosphorus tended to be lower when using rich phosphor coppers. The authors show that the redistribution of the phosphorus depended upon the rate of cooling. It might also depend to a certain extent upon the temperature of the copper at the time of adding the phosphor-tin, and upon the relative weights of the latter to the copper, as such factors were known to influence the rate of diffusion *before* the solid condition was attained. Knowing the variety of procedures possible in the foundry practice made him (Mr. Parker) question whether the diffusion and decomposition was sufficiently instantaneous to suit some of them. An example of this was seen when using phosphor-tin. This was added to the crucible *after* it had been drawn from the fire, and then chilled castings were rapidly cast with the mixture. When making castings for Admiralty Phosphor bronze bearings (specified to be made with 85 per cent. copper and

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* " Iron, Steel, and other Alloys," Professor Howe, p. 41.

15 per cent. of phosphor-tin, and to contain *not less than* 0·45 per cent. of phosphorus *in the castings*), the temperature was kept throughout as low as possible. The copper was barely melted before adding the phosphor-tin. This addition at once rendered the metal sufficiently fluid, and, taking advantage of this, "overheating" the alloy was prevented. The mixture needed to be thoroughly stirred before pouring. The writer believed that modern practice in general was, to pour as cold as possible, and cool rapidly in order to obtain strength, for although a tensile test was not always specified, it could not be expected that weak castings would be accepted. The question was of practical importance, for at first sight all the above procedure seemed to tend one way, namely, to produce castings containing more phosphorus present in the " Alpha " solid solution than present as copper phosphide, free, or in the ternary eutectic. He desired to know whether that was really so? Also, did it produce the copper-tin-phosphorus constituent in a finer grained condition, and also *impurer* and therefore *harder?* A definite statement from the authors upon this point would be of value, for if that action occurred, then the treatment was antagonistic to the ideal structure of a bearing metal as usually defined, namely, a plentiful distribution of hard eutectic or compound in a *soft* " Alpha " solid solution (see p. 169). Referring to p. 164, it was not quite clear what was meant by the copper in the phosphor bronzes "—did this refer to the copper present as the " Alpha " solid solution? The effect of foundry treatment could not be interpreted from Fig. 3, because it represented (as nearly as experimentally possible) the constitution of the bronzes at absolute equilibrium obtained by extremely slow cooling—*i.e.* by conditions undesirable in foundry practice, and fortunately rarely obtained accidentally. The thinner the castings, the lower the castings temperature, and the smarter the handling of the metal from " mix " to " pour," the greater would be the divergence of its microstructure, when cold, from that shown in diagram, Fig. 3. The object of the research appears to be to ascertain whether those alloys containing, say, more " Alpha " constituent than others, were stronger or weaker, more ductile or less, and so on, taking each main constituent in the phases normal to the composition and normal to any specified condition of manufacture. The research had not yet reached that stage—in fact, it was a very big undertaking to furnish it. The authors started work on the " dead soft " or " annealed " end of the scheme, probably by far the best thing to do, but meanwhile he expected that members interested in the " trade " would quite naturally desire more mechanical tests, and especially photo-micrographs, of the commercially useful alloys in commercial conditions. He regretted that he had none of the latter at hand to offer. Although the results of the unfinished research might contain the key to the puzzle, it was not easy to apply them to interpret the products of commerce, and troubles connected therewith. Therefore, personally, he would greatly appreciate a cooling curve of the standard Admiralty bearing alloy mentioned previously. It was probably already generally known, although he had not seen it in print, that that Admiralty alloy, made as indicated above, gave 16·8 to 17·5 tons per square inch with no elongation on 2 inches gauge length

when cast in iron chills ; whereas bars of the same size ($1\frac{5}{8}$ inch diameter) cast in dry sand only gave from 13·5 to 16·0 tons per square inch with about 0·5 per cent. to 2 per cent. elongation. The elastic limit was almost identical with the maximum stress. The chilled bars had a dense silvery-grey fracture, while the sand bars showed some copper-coloured crystals. When the research had also dealt with the "rapidly cooled or hard " end, the two parts together would be extremely useful. They would explain the marked differences in strength of castings of similar composition but made by different foundries following their pet methods of production, and would afford guidance to the best method of producing any particular mechanical property. He would call attention to the fact that neither Mr. Philip's paper,* nor the authors', referred to the interesting chapters on phosphor bronze given by Professor Thurston in vol. iii. of his book, *Materials of Engineering*. Doubtless other readers of the paper besides himself desired more details respecting the methods used to identify the eutectics microscopically. He inferred that the heat-tinting method mentioned in Mr. Law's book on *Alloys* was used, but he had not given working details, and Behren's in his *Microchemical Analysis* did not deal specially with phosphor bronzes. With reference to the addition of lead to phosphor bronzes (pp. 169 and 170), in most cases he (Mr. Parker) found that the minute globules of lead were not "evenly distributed throughout the mass," but were confined to the eutectic. That was also the case in dry-sand castings of copper-tin bronzes containing 13 to 15 per cent. tin and from 0·1 to 0·9 per cent. lead, but NO *phosphorus*. From a practical standpoint that was as it should be. The lubricant (lead), if necessary at all, should be present at the points of actual contact which *carry the load*, for what use would it be if sunk in the (microscopical) hollows of the worn-down soft matrix ? He looked forward to the next part of Messrs. Hudson and Law's research with much expectation.

The AUTHORS wrote, in reply, that from the remarks of one or two members, there appeared to be some slight misunderstanding of the scope of their paper. They made no claim to have established a complete equilibrium diagram, the intention of the paper being to show what was the general constitution of those alloys under approximately normal conditions. Although the authors hoped to be able at some future time to publish the results of their work in the direction of establishing the complete constitution of those alloys, the magnitude of the task and the pressure of other work made it uncertain when such a course would be possible. On the other hand, it was thought that the publication of some of the conclusions arrived at after a fairly lengthy acquaintance with those alloys might give rise to a useful discussion, and serve as a reasonably accurate guide to others. The formation of what had been called in the paper the triple eutectic was a point of considerable theoretical interest, but it was thought that a discussion of the possible complications involved in the formation at

* *Journal of the Institute of Metals*, 1909, No. I., vol. i. p. 164.

500° C. was hardly necessary at the present stage. The explanation given by Mr. Edwards and Dr. Rosenhain (which was in agreement with the authors' views) of the mechanism of the formation of that constituent was no doubt the correct one, and it must be admitted that it was incorrect to speak of it as a "ternary" eutectic, as that expression had already been applied to cases in which a eutectic was formed by the simultaneous deposition of three constituents. On the other hand, it would be equally incorrect to describe it as a binary eutectic, and since, under all ordinary conditions, that eutectic was seen to be made up of three distinct constituents, it was thought that, in the absence of a better expression, it was justifiable to call it a "triple" eutectic. Perhaps a term such as "triple eutectoid" would be more applicable to such a case, where a constituent, although separating as a binary eutectic, undergoes a change whereby it passes into a distinctly eutectic-like constituent composed of three substances. Since the paper was written the authors had had the opportunity of investigating that question a little more fully, and the two photo-micrographs reproduced seemed to show the correctness of Mr. Edwards and Dr. Rosenhain's views. A phosphor bronze, made up to give an alloy consisting of "triple" eutectic and some excess of α, was allowed to cool slowly in an electrically heated (Kryptol) furnace to a temperature of 550° C. The button of alloy, weighing about 25 grams, was then withdrawn from the crucible by means of the couple-tube round which it had solidified, and quickly plunged into cold water. A piece broken off this quenched specimen was then polished and etched with a hydrochloric acid solution of ferric chloride. Fig. 6 showed the structure at a magnification of 1000, and it would be seen that the eutectic appeared to be made up of only two substances which were Cu_3P, the white substance, and what was probably β, the black substance, although no distinction was apparent between the primary α and the β of the eutectic. A small piece of the quenched alloy was then annealed for half-an-hour at a temperature of about 550° C., and its structure, after polishing and etching in a similar manner, was shown in Fig. 7. It would be seen that the β has now undergone the change to $\alpha + \delta$, and that the eutectic had the usual triple structure seen in normally and slowly cooled alloys.

In answer to Mr. Bengough's question as to the rate of cooling, the diagram given on p. 165 was made up principally from the examination of alloys which had been used for cooling curve experiments in which the rate of cooling averaged about 12° C. per minute between 800° C. and 600° C., and of course correspondingly slower at lower temperatures. The cooling curves were taken of some forty alloys, the composition of which varied within the following limits: Tin, 0–14 per cent., phosphorus 0·5–6·5 per cent. In addition a number of other alloys were prepared in a laboratory wind-furnace, and allowed to cool down with the furnace. The materials used in making the alloys were: (1) Electrolytic copper; (2) phosphor copper (12 per cent.), made from electrolytic copper and red phosphorus; (3) best quality refined tin. The extent to which phosphorus or Cu_3P was soluble in copper containing
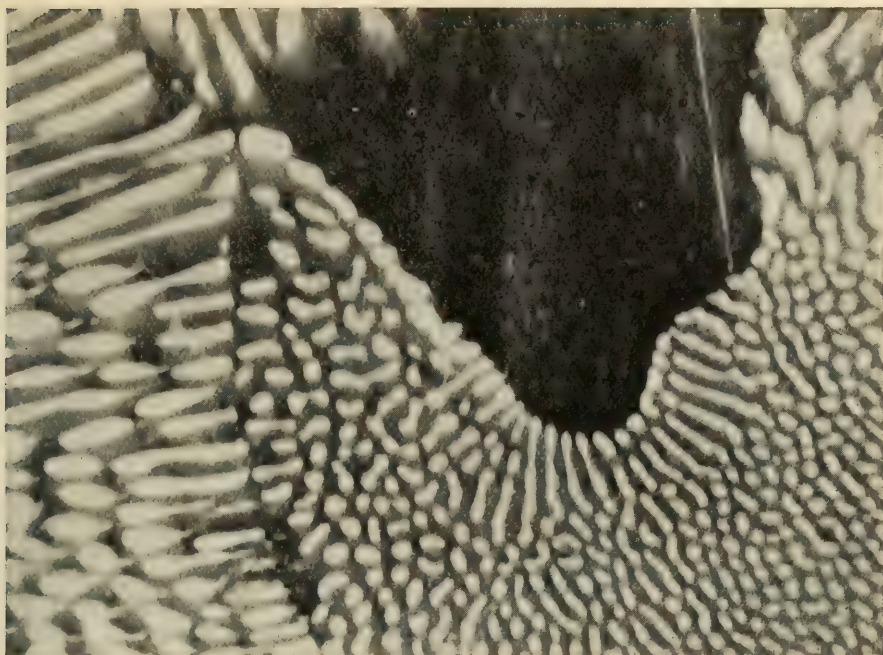
FIG. 6.—Quenched at 550° C.   Magnified 1000 diameters.
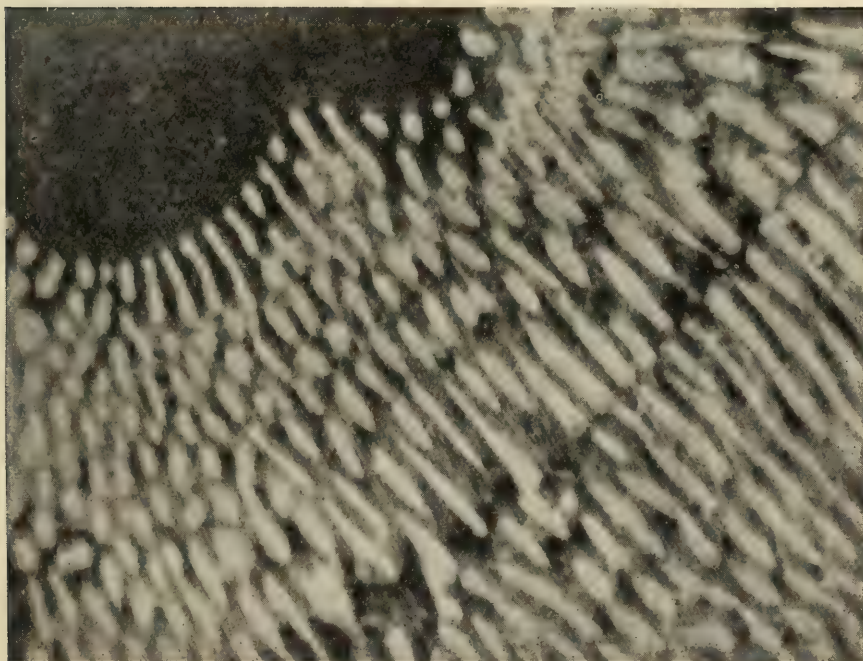
FIG. 7.—Annealed at 550° C.   Magnified 1000 diameters.

tin appeared to be of the order of 0·25 per cent. in an alloy containing 6 per cent. of tin, as the chill-cast alloy of that composition had an almost homogeneous structure after annealing for an hour at 550° C. The question of the time and temperature necessary to give complete homogeneity was a little difficult to answer definitely, as there were other conditions that had to be considered. Thus chill-casting and rolling or otherwise working would assist in the production of homogeneity on subsequent annealing.

In reply to some of the questions raised by Mr. Parker, and not already dealt with, it should perhaps have been more clearly indicated that the area $A\imath y$ of Fig. 3 referred more particularly to the constitution of those alloys after annealing, and that in any *casting* it was unlikely that 0·05 per cent. of phosphorus would be found in solution in the a. The statement that the usual procedure in casting the bearing bronzes, viz. low casting temperature and quick cooling, "tends to produce castings containing more phosphorus in the Alpha solid solution than present as phosphide" was certainly not correct. The question of the possible small amount of phosphorus in the a solution would hardly be likely to affect seriously the properties of bearing metals. In the analytical work it was found that the relative amounts of tin and phosphorus present in the alloy rather than the condition of the phosphorus determined whether all the phosphorus was found with the tin oxide. Thus if the amount of tin was less than ten times that of the phosphorus, an appreciable amount of phosphorus was found in the acid solution.

Mr. Parker appeared to be under the impression that the alloys employed by the authors were cooled abnormally slowly, and that the structures were therefore not comparable with those occurring in actual practice. That, however, was not the case. The appearance of a large and slowly cooled casting only differed from that of a small and quickly cooled casting in possessing a coarser structure, *i.e.* the constituents occurred in larger masses. Otherwise they were the same, and the conditions chosen by the authors were not dissimilar from those obtaining in practice. A large number of industrial alloys had been examined and photographed, and had there been any difference in the structure of those alloys as compared with the experimental alloys of the same composition, either the methods of research would have been modified to bring them more nearly to actual working conditions, or else the difference would have been given due prominence in the paper.

THE FAILURE IN PRACTICE OF NON-FERROUS METALS AND ALLOYS

WITH PARTICULAR REFERENCE TO BRASS LOCO-TUBES

By T. VAUGHAN HUGHES, A.R.S.M., F.I.C.

BELIEVING that the welfare of the Institute of Metals will in some measure be promoted should members from time to time contribute short papers on abnormalities or "breakdowns" in those metals and alloys which come under their purview, the author ventures to bring this brief notice before the Institute with the consent of the parties for whom the investigation was originally made, and to whom he tenders his thanks.

Having exhausted all the usual methods of investigation into the cause of the frequent bursting of the brass loco-tubes, which form the subject-matter of this paper, the engineer and managing director considered that further enlightenment was necessary, and the author was instructed to endeavour to discover the cause of repeated disasters which ended in serious casualties and Government inquiries.

The first tube submitted to the author was received in two parts, the larger 3 feet 5 inches and the other 2 inches over all. The pieces fitted one another along a line of fracture. The tube had been externally scraped and wiped so that the metallic surface on the outside was exposed. A working pressure of 160 lbs. per square inch was carried in the boiler in which the tube was fitted.

The outside of the tube in contact with the boiler water was quite free from corrosion of any kind. The inference is that the boiler water was free from substances capable of corroding the alloy (70/30 brass) of which the tube was composed.

No part of the exterior of the tube exhibited evidence of having been "burnt," *i.e.* overheated and oxidised.

The inside, however, was much corroded from end to end —the greatest corrosion had taken place near the fracture, which, in place, lay nearest the fire-box.

The walls of the central and least corroded portion of the tube were 0·1 inch thick. About the area of fracture the least measurement gave a thickness of only 0·038 inch.

The whole of the interior of the tube was coated with a lightish green salt, practically insoluble in water, but easily in dilute sulphuric acid. A further investigation of this salt scraped from the interior led to the conclusion that it was mainly composed of mixed basic sulphates of copper and zinc.

After removing the green coating by dilute sulphuric acid a dark red "scale" appeared, formed of cuprous oxide. Examined under a high magnifying power, this layer of oxide was permeated with the light green salt referred to.

So far it is reasonable to infer that the cause of fracture of the tube under working pressure was due to—

(1) Corrosion proceeding from the inside towards the outside of tube.

(2) That the tube had not been "burnt," *i.e.* overheated and oxidised, as cupric and zinc oxide were absent in the "scale" and salts.

After sawing the tube longitudinally and opening, it was observed that the corrosion was not continuous throughout the length of the tube, being more marked at the ends, and particularly at the fire-box ends, and on one-half of the inside circumference.

An exhaustive microscopical examination (1-inch lengths) of the tube, longitudinally and transversely, was made. The crystal grains were found to be larger at the ends than in the middle parts.

About the area of fracture the crystal size was equivalent to that produced by maintaining a 70/30 brass of equal dimensions at a temperature of 800° C. for about ten minutes. The crystal size at the end farthest removed from the fracture was smaller, resembling that of an

equal dimensioned piece of brass heated for ten minutes at 700° C.

The central portions of the tube were normal, both longitudinally and transversely, proving that the tube had been annealed at about 600° C.

A peculiarity of the crystals at the seat of breakdown lay in the fact that they were uneven. Those nearest the fracture were much larger than in an area 90° to 180° from it. The boundaries of the largest crystals were corroded, and embraced intrusions of cuprous oxide.

Obviously, then, the tube as supplied by the makers was passable as a commercial production. Slight overheating had taken place at the ends of the tube—possibly for expanding purposes. Abnormal overheating, however, had occurred near the fracture, which, as explained above, abutted the fire-box.

As the temperature of the water due to the boiler-pressure used was about 360° Fahr., it might have been advisable to anneal the tube in process of manufacture at as low a temperature as possible. However, the manufacturer is not to blame here, as large crystal grains would have been formed in other portions of the tube had it been unevenly or over-annealed in the mill. The overheating had taken place after the tube left the manufacturer.

A chemical examination of the coke used as fuel proved it to contain 0·89 per cent. of volatile and 0·37 per cent. of sulphur fixed in the ash. Such a coke would supply all the sulphur necessary for bringing about above results.

The inquest on the tube so far has shown that by overheating of the ends of the tube, particularly the fire-box end, the grain structure has been so enlarged that incipient disintegration has taken place—that is, the texture has been enlarged, and the crystal boundaries become permeated with films of lower oxides, thus undermining the strength of the alloy.

Can the abnormal corrosion be explained ? A word or two anent the method of working the boiler. Steam blast was used for producing draught. As coke was the fuel, the interior of the tubes would be subjected to intermittent

streams of hot gases containing gaseous sulphur compounds—
carbon monoxide and dioxide. The proportion of the latter
gases would depend on the size and volume of the fuel in the
grate.

Two alternative explanations appear applicable.

The first may be called shortly a " low temperature " theory.

Allowing the ends of the tube to have become overheated
—the evidence shows them to have attained a temperature
much above the melting-point of zinc—it is reasonable to
conclude that the zinc on the surface layers of the interior of
the tube had evaporated.

A similar result is brought about when rolls of hard brass
are subjected to a prolonged annealing in a reducing atmos-
phere at a temperature about the melting-point of zinc.

As the hot gases passing through the tubes consist chiefly
of nitrogen—carbon dioxide and monoxide—the latter would
tend at times to maintain a reducing atmosphere and cause
cuprous oxide to be formed rather than the higher oxide.
The joint action of steam and sulphur dioxide, evolved when
the fires were made in the morning or at intervals during the
day, using damp coke, coming in contact with the cooled
cuprous oxide covered surface, condense and react, especially
if a little cupric oxide was also formed. Thus arise the sul-
phates—basic in character, as above investigation shows. The
cuprous oxide layer being meshed suggests such formation as
following evaporation of one constituent of a crystalline mass.
The sulphates being once formed, repetition of the combined
actions would cause the corrosion to continue until breakdown
of the tube occurred at the fire-box end where the reactions
would be most pronounced.

The second may be shortly referred to as a " high tempera-
ture " theory.

The evidence shows the tube in certain parts to have
attained the temperature of about $800°$ C. Interaction be-
tween the hot carbon monoxide, gaseous sulphur compounds,
and the copper and zinc of the tube could take place. The
tendency would be to form cuprous oxide in view of the
metallurgical action of cupric oxide, reducing gases and sul-
phur compounds under the conditions obtaining.

This cuprous oxide would appear to be the vanguard of the attack. The cooler and moist sulphurous gases generated after stoking wet fuel on to the grate would be the rearguard, and form the sulphates referred to above.

There was no evidence of carbonates in the green incrustation.

The heating and cooling of the fire-grate would take place several times a day under special conditions of traffic.

This occurred regularly on two sections of the route in a fifteen-minutes' service. At the top of two gradients of 1 in 17 to 20 the locos were brought to a standstill for steam-raising purposes. It appears to have been the habit of the stoker to charge damp coke on to the white-hot bed of fuel in the grate during these stoppages. Thus the cooling and formation of large volumes of carbon monoxide can be accounted for.

The evidence of the contemporary presence of the basic salts of copper and zinc, and particularly of the layer of cuprous oxide in contact with the tubes, negatives the theory that the bursts of the tube followed corrosion of the alloy by impacts of particles of coke and ash, induced by the steam-blast.

As stated above, the tube submitted for examination had been externally scraped and wiped.

On close inspection a chocolate-coloured film could be detected in places.

As the author was not satisfied with the cause of the over-heating of the tubes—and as the ends presumably had been expanded in the cold and no reheating of any kind resorted to in the loco-shed when fixing new tubes in the boiler—he advised further investigation; and as a result several tubes from the same boiler were sent for examination. They were delivered to the author neither scraped nor wiped.

The tubes were externally covered from end to end, where in contact with the boiler water, with a chocolate-coloured deposit, even and bright.

The average thickness of this covering was about $\frac{1}{10}$ milli-metre. In order to avoid contamination with iron, and to reduce as much as possible admixture of the scrapings

with abrasions of the tube itself, a hard copper scraper was used.

On scraping it was noticed that the deposit was formed in a series of layers. The innermost, or that nearest to the metal of the tubes, was almost black and very compact. In hardness the chocolate-coloured deposit resembled that of talc. The innermost layer required considerable force to remove it. In fact it resembled, in general characteristics, a hard varnish.

By scraping a large number of tubes, similar in all respects as to the amount and character of deposit, sufficient for a fairly exhaustive analysis was obtained.

A preliminary test proved that up to 100° C. moisture only was dissipated from the material. Consequently the bulk was heated at 100° C. until constant in weight.

A portion of this was extracted with water. The extract yielded chloride and sulphate of lime only.

The dried portion was extracted with alcohol. This rendered a soap containing iron, alumina, and magnesia as bases.

The residue after the alcoholic extraction was then extracted with dried ether. On evaporating a grease, fluid at ordinary temperatures, was obtained. At a later date several pounds of this chocolate-coloured deposit were procured. On more extended investigation this grease proved to be a heavy, mineral hydrocarbon. Such is used as a cylinder lubricant. The locomotives from which the tubes were removed were broken up a year or two ago. The author has recently been informed that a quantity of cylinder oil was found in the water-tank, having found its way there by the carelessness of the attendants.

The doubly extracted dry residue was subjected to analysis.

In the first place it was incinerated in a stream of purified oxygen and air by the ordinary methods of organic analysis.

Weights of carbon dioxide and water were obtained: the former calculated to carbon in carbonaceous matter (as there was not the slightest trace of carbon dioxide apparent on heating the dried substance with dilute acids); the latter assigned to combined water and hydrogen in combination with the carbon most probably.

The residue after combustion was submitted to analysis with results given below :—

	Per Cent.
Loss at 100° C., *i.e.* moisture	2·80
Matter soluble in water (chloride and sulphate of lime) . .	1·65
Alcoholic extract (a soap containing iron, alumina, and magnesia)	1·34
Ether extract (rendering a grease fluid at ordinary temperatures)	0·50
Carbon as carbonaceous matter	5·98
Combined water and hydrogen	15·59
Silica	19·21
Magnesia	16·77
Ferric oxide	13·23
Copper	8·18
Zinc	8·35
Alumina	2·41
Lime	2·45
Sulphuric acid (as SO_4)	1·85
Phosphoric acid (as P_2O_5)	0·32
Chlorides	trace
Alkalies	nil

A few observations on the above analysis are desirable. No salts of either copper or zinc were found in any of the extracts.

A proportion of zinc appears to have been present as basic sulphate. A proximate analysis on a very small quantity led to the conclusion that a portion of the copper found was present in the deposit as an oxide. The balance of the copper and zinc approached the composition of the tube (70/30 brass), indicating that scrapings of the tube itself had become admixed with the sample of "scale."

The brass fittings on the boiler might account for some of the copper and zinc.

The carbonaceous matter (5·98 per cent.) is apparently that derived from the carbon in the innermost varnish-like layer.

There were no carbonates in the "scale," nor were there carbonates formed when the extracted deposit was calcined in the air.

Over thirty measurements of the thickness of the "scale" were made. They gave an average of 0·09 millimetre— the maximum being 0·11 and the minimum 0·07 of a millimetre.

It was thought that a measurement of the electrical

resistance of this deposit would give some indication of its heat conductivity. Consequently the coating on a dry tube was subjected to an electromotive force of 250 volts.

The electrical resistance offered by this coating was 20 megohms. Several measurements were made before the tubes were scraped, with as nearly as possible the same result.

When the coating was damped by a drop of water where one electrode touched it, the resistance fell to 150,000 ohms only.

The test is instructive as indicating that, even when damp and cold, the coating forms an excellent non-conductor of electricity, and we may reasonably conclude of heat also.

Since the above investigation was completed several pounds of a chocolate-coloured, frothy mass were obtained from stays and bracings in the same boiler. The stuff contained a total of 6 per cent. of organic substances extracted by alcohol and rectified petrol.

The peculiar nature of the deposit on the tubes, the author believes, is sufficient to account for the overheating referred to in this paper, and for the corrosion ending in explosion. In this instance we have shown that the material has broken down in the hands of the user and not by any aberrations on the part of the maker.

It is noteworthy that the boilers from which the tubes were taken, and others in which similar accidents occurred, were fed with the untreated water supplied under the Birmingham Welsh Water Scheme.

The author is informed that abnormal breakdowns in the loco-tubes did not occur when the old supply was used for feed-water.

The opinion and criticisms of members will be very welcome.

DISCUSSION.

Dr. W. ROSENHAIN (Teddington) thought that the author was quite right in the remark he made in the opening sentence of his paper, that it was extremely valuable and important for the Institute to discuss cases of breakdown of the kind described, and he thought it was particularly useful that the author should come forward with a theory accounting for the breakdown and place it before the members as freely as he had done for criticism and discussion. Having said that, he proposed to avail himself of the opportunity of discussing the paper, and he hoped the author would take any remarks he made in exactly the same spirit in which he (Dr. Rosenhain) took the paper. The first point that occurred to him was that it was a little difficult to accept the view that a film of thermally non-conducting material only $\frac{1}{10}$ millimetre thick should so enormously retard the flow of heat from the flue gases to the water through thin tubes only $\frac{1}{10}$ inch thick as to allow the temperature on the fire side to attain 800° C., or anything like it. He was not prepared to say that could not happen, but it was a little difficult to believe it off-hand, and one would like to see the clearest demonstration of it before doing so. He desired to ask the author whether he had examined other tubes, from which he had scraped the deposits, microscopically near their fire-box ends. He knew it would not be possible to examine them all in that exhaustive way, but if the theory the author had advanced was correct, the overheated structure ought to be found at or near the fire-box end of any one of the tubes which was coated in that way on the inside. If that was the case, it would be almost conclusive evidence in favour of the author's theory, but unless that was so, one would have to look for the overheating somewhere else. He did not quite see that, apart from that particular item of evidence which was not contained in the paper, the author was justified in concluding that the overheating could only have taken place after the tubes left the maker—either the maker of the tubes or the boiler. His reason for saying that was, that he had had occasion to examine quite a number of brass tubes and boilers, in several cases condenser tubes and not locomotive tubes, and one at any rate failed under vibration. It was a condenser tube in a fast-running ship, where there was a very considerable amount of vibration, and it was found that that tube had been locally overheated at a temperature somewhere about that indicated by the author, and the general photographs of the microstructure of the specimen closely resembled the case described in the paper. There was no possibility of the tube having been overheated to 800°, or anything like it, in the ship; it must have happened under manufacture, so that the possibility of local overheating having occurred was not quite excluded. It might be of interest to say that the similarity of the two cases went so far that the overheating was visible, and very much more marked, at any rate on one side of the tube than on the other, exactly as appeared to be the case in the author's tube. He wished to ask two further questions that occurred to him. First

of all, he should like to have, if possible, the complete analysis of the brass, the reason being that he had found in a large number of cases that the presence of a somewhat large quantity of lead—by which he meant something over 0·3 per cent.—caused local corrosion, either under the action of corrosive liquids or of corrosive gases ; and the question of the lead content of the brass was rather an important one from that point of view.   Finally, if local overheating really was the cause, and actually did occur in the boiler, why did it lead to corrosion rather than to fracture ?   He took it, from the description given in the paper, that the tube was thinned down by corrosion and then broke ; it did not corrode right through.   He supposed it broke because of those two things.   The really interesting point was, were the other tubes also affected as regards their microstructure in the same way ?   The case was a most interesting one, and the members were exceedingly indebted to the author for bringing it before them in the very clear way in which he had done.

Professor T. TURNER, M.Sc., Honorary Treasurer, said the question of the corrosion of locomotive and similar tubes was one of very great importance, as he believed most of the members were fully aware. Sometimes it was extremely difficult to decide, even on inspection of the tube, as to the most probable cause of a failure such as the author had indicated to them.   His experience was that in a large number of cases the part of the tube that was in contact with the water was absolutely unaffected.   He believed, however, he had heard that the President's (Sir Gerard Muntz's) experience had been the contrary, and that he had often had tubes corroded by the water ; but speaking from his own experience of a smooth tube like the one exhibited, it was absolutely unaffected by the water to which it had been exposed.   The interior of the tube was often attacked to such an extent that it was no thicker than a piece of notepaper, and then, of course, it had reached an extremely awkward and dangerous stage.   There were various causes that might account for that thinning, one of which was the abrading effect of the particles of slag or clinker with blast under pressure. Then there was also the question of the influence of chlorine in the furnace gases.   He knew the common idea was to put it all down to sulphur, and they put it down to sulphur, very much like the puddler and other metal-workers used to speak of sulphur as the great remedy, or great bugbear, as the case might be, for everything.   But if the greenish deposits which formed on the surface of locomotive tubes which were corroded were examined, it would not infrequently be found that an appreciable amount of chlorine was left in the residue.   The effect of chlorine at a high temperature on the surface was to form chlorides which were partly volatile, or which were easily abraded and carried away by the slag, the effect he believed being that, as a general rule, if coals which contained much chlorine were taken, it would be found that in that neighbourhood there was also great corrosion of the tubes.   His experience, too, exactly agreed with what Dr. Rosenhain had said in reference to the proportion of lead.   It had frequently

been found that with high proportions of lead, over about 0·35, the tubes were more likely to go wrong, but he had had cases of corrosion with absolutely good tubes made of the purest commercial material, and those cases, as he had said, were sometimes difficult of explanation. With reference to local overheating, the tubes in the first place, as finished by the manufacturer, were cold drawn ; but as the ends had to be expanded, it was a common practice, he believed, to anneal those ends in an open fire. It was his belief that a good deal of the damage was done by this last annealing, which might be done in an unskilful manner, and which might easily give the effect which Dr. Rosenhain had referred to, of being more annealed on the one side than on the other. Mr. Hudson was connected with him in an inquiry of that kind a little time ago, and on cutting down a tube, starting from near the centre of the tube and coming to the end where it had been expanded, it was found that the expanded end was distinctly more coarsely crystalline in character, and showed the effects of slight, though distinctly important, overheating. The subject was one that should be of very great interest to the members of the Institute, but he had no time to refer to many other points that might be mentioned.

Professor A. K. HUNTINGTON, Vice-President, thought it was impossible to bring a subject of greater importance before the members of the Institute, as it was one on which there was a great confusion of ideas, and statements as well. One of the greatest difficulties was to get a correct statement of the facts of the case. But although the subject was very important, he did not think the paper helped one along very much, and personally he did not agree with its conclusions. He thought the probable cause of the trouble was to be found in the annealing, which was a source of a great deal of the trouble in such matters. In dealing with a comparatively thin tube, the arrangements made for getting the exact temperatures were not always what they should be, and sometimes the results were not satisfactory. It was very valuable to the Institute to have such a paper brought before it, because it enabled the users and the manufacturers of the article to discuss the question ; but the difficulty was to get any properly connected and continuous account of anything that was used in practice, and until that was done not very much advance would be made.

Mr. H. L. HEATHCOTE, B.Sc. (Coventry), referring to the question of the temperature reached by the tubes, said that Dr. Rosenhain had expressed his conscientious doubts as to the possibility of the temperature required for overheating being reached. In a paper read by Dr. Hatschek at the Society of Chemical Industry on the previous Monday evening on oil-water emulsions, mention was made either by him or by one of those who took part in the discussion of some experiences due to the oil which got into the feed water. The film of oil would probably be very thin, but it was stated to be sufficient to enable copper tubes to reach such a temperature that globules of molten copper were formed on the fire side. This would mean, he supposed, a temperature of something like 1000° C.

Mr. C. A. Klein (London) desired to emphasise Professor Turner's remarks, because he thought there was a tendency to ignore the question of chlorine. He had the point driven home to him very forcibly in connection with the manufacture of Mond gas. There was a considerable quantity of ammonia produced in the process, and the gas as it left the producer was washed by water. After about five years' work it had been found that the first washer was eaten through, and from it were hanging long crystals of ammonium chloride, which had been the cause of the trouble. He had come to the conclusion that the presence of chlorine in coal should be more generally realised.

Mr. G. D. Bengough, M.A. (Liverpool), said it seemed to him that if the overheating took place during the expanding process—he understood Mr. Vaughan Hughes to say it was expanded cold—but even supposing it was expanded hot, unless the brass was heated to an exceedingly high temperature the strength of the brass when it had been cooled down again to the ordinary temperature would not be very seriously impaired. Mr. Hudson and himself had carried out a considerable number of tests of brass, and found that if the brass was cooled down again after heating to temperatures somewhere in the neighbourhood of 650°, the strength was very little impaired indeed, but if the brass was subjected to stress *at* high temperature, *i.e.* if it was heated in practice to a temperature of 650° or anywhere near it, the strength would be very seriously impaired indeed, and it would fail readily. In the case considered by Mr. Vaughan Hughes, it seemed to him that the overheating if it occurred during expanding would not have much effect, but if it occurred during the actual time in which the tube was being worked or strained by steam pressure or in any way, it would be very serious.

The speaker was, therefore, inclined to agree with Mr. Vaughan Hughes that overheating due to scale formation, combined with local corrosion, were the causes of the failure. There was one other point in connection with chlorine to which he wished to call attention. Professor Turner had remarked that in some cases the corrosion took place on the water side, and in other cases on the other side of the tube. It seemed to him that corrosion would be liable to take place on the water side when the water used was sea-water, as in the case of marine condensers, but where fresh water in locomotives was being dealt with, then the corrosion seldom took place on the water side, unless the water used was unusually impure, or contamination of the coal or water with sea-water possible. He wished to endorse what Professor Turner said about the presence of slag. A small amount of slag, a mere trace, had very great influence indeed in impairing the strength of the tubes, and also in starting corrosion; it gave a loci for the beginning of corrosion. In particular in the neighbourhood of slag a tube would break if it was subjected to vibration to any great extent; it gave a loci for a crack to start in that way, but he did not think that seemed to be the cause of the failure of the author's tubes. He wished that the author, instead of giving the sulphur fixed in the ash of the coke, had given the total

sulphur in the coke, so that it would have been possible to deduce the total amount of sulphur that was likely to be volatilised and appear in the gases as sulphur dioxide, because that would be the sulphur which would set up the corrosion which took place in the tube. He did not quite agree with the author that the tube could ever have reached a temperature of 800°. If it had, that alone, in his opinion, would account for the failure of the tube; if the tube had got anywhere near that temperature during use, it would have broken down at once. A point here seemed to him to be that it was possible to imitate a structure represented by ten minutes at 800° by a longer period of annealing at a very much lower temperature. Tubes in locomotives of the kind referred to must be submitted to moderate temperatures for considerable periods, and the crystals would grow; so that it seemed to him it was impossible to deduce from the size of the crystals the temperature to which the brass had been heated, because a long period at low temperature was equivalent to a short period at a higher temperature. In conclusion, he wished to endorse what the other speakers had said as to the interest and utility of papers of such a kind as this to both the scientific and practical members of the Institute.

The PRESIDENT said that as Professor Turner had referred to what was particularly his (the President's) own business, he felt he must at least say a few words on the subject. With regard to the author's suggestion as to how the overheating occurred, he was bound to confess that up to date he was not sufficiently satisfied with his theory to accept it. He did not say, like Dr. Rosenhain had done, that it could not happen, but he did not think it did happen. The overheating would probably occur in one of two ways, either in the annealing in the manufacture of the tube, or in the subsequent use of the tube in the boiler. In the experience of his firm as tube makers, it had been found that cases of overheating were obtained from time to time, and in almost every case the tubes came from boilers which were used in works yards or colliery yards, where the boilers were more or less carelessly used—in a more happy-go-lucky way than would be the case on a main line of railway. It had been ascertained once or twice that the trouble occurred through the man in charge letting his water in the boiler down in the evening and leaving the fire in. That, of course, was not good for the tube; it burnt the tube, and it was condemned. Above the point where the water had gone the tubes were spoilt. He had run up against a case of that nature. With regard to annealing, of course the tube might be spoiled in the works during annealing, but, on the other hand, it must be recollected that in the case of the locomotive tube it was supplied in the hard-drawn state from its last pass, and it was very improbable that the tube had been burnt, as, had it been burnt, it would not have stood the final pass on the draw-bench. There was a probability of a tube on being annealed at the ends for expansion cold, and re-annealed subsequently to enable it to be placed in the boiler, being overheated; it must be re-annealed, otherwise it would not expand to the plate. That was one of the troubles which had to be faced. Going

back to Professor Turner's remarks, that gentleman stated that the corrosion in tubes almost always took place on the inside of the tube. He was very diffident and careful in venturing to put a professor right, but in the present instance he thought he must do so. He had known tubes corroded absolutely clean through from the outside till they were like sieves, more especially on the locomotives of the South American railways, owing to the nature of the water used in them. It was also found on the railways of this country in various parts that very bad corrosion was caused on the outside of the tubes owing to the quality of the water used. The fresh water used in the boilers was not always so fresh as it might be ; in fact, the railway companies had great difficulty in getting water which was suitable for their requirements. A few of the railway companies were very fortunately placed, having an excellent water supply, but other companies, particularly the Midland Railway Company, experienced great difficulty with their tubes. But although there was corrosion from the outside, it was absolutely distinct from the corrosion from the inside. It might be said that the trouble occurred owing to the composition of the tubes, but he did not think that was the case. A tube which would stand for outside work might not stand for the inside work. He was sure Professor Turner was perfectly correct with regard to the remarks he had made on the subject of chlorine. When old tubes were returned to the works, chlorine as well as sulphide were found in them, both of which were very serious causes of corrosion. The fuel question was one that required great care and close attention, and in fact it received it from locomotive people ; they were all careful as to what fuel they used, and selected it as well as they possibly could. The result of the chemical corrosion, the formation of chlorine in the tube, was slight surface roughness, the ultimate result of which was that the abrasion from the cinders cut away the surface which had been formed, and started a scoring of the tube, which, if continued, would very soon wear a considerable hole in it. It was found in his works that the trouble in the tubes was as a rule on the two sides near the fire-box end ; first of all on the lower side of the tube just inside the ferrule, and secondly, some 3 inches or 4 inches further in on the upper side. Practical evidence was at hand of what had happened. The blast brought up the cinders from the fire, an impingment against the ferrule took place, and the ash then went down on to the inside of the tube, and bounced up again to the top of the tube. In some cases where the tubes had been used for a great length of time, holes were made in the tube ; they were cut right through. He did not think lead played much part in the question, because he had known absolutely pure tubes fail just as badly from corrosion as tubes that contained lead. Dr. Rosenhain had referred to the question of condenser tubes, but it was very important not to confuse the two questions of condenser tubes and locomotive tubes, because they were absolutely distinct. Two different sets of circumstances and conditions applied in those cases, and he hoped therefore the members would altogether leave lead out of the question so far as the action of corrosion went. He did not think he need trespass further upon the time of the members. The subject the author had

brought forward was one upon which he could speak comfortably from the present time to the next week.   One of the greatest objects of the Institute was that the members should be able to learn from each other, and he was sure the discussion on the present paper had opened up a field which might be followed up with great advantage.   The Institute was much indebted to Mr. Hughes for bringing the paper forward, and he hoped by means of such papers the practical and scientific men would be brought together for the purpose of arriving at a conclusion with regard to what had really occurred.

Mr. T. VAUGHAN HUGHES, in reply, said he was exceedingly obliged to the President and the other speakers for their remarks, and thanked them most sincerely for the very kind criticisms they had made of his paper.   He hoped the few observations he had made would bring about the result which the President had just expressed, and that they would bring practice and theory more closely together.   With regard to the various points raised in the course of the discussion, he would endeavour without taking individual references to answer them seriatim.   Dealing first of all with the fuel question, the fuel used happened to be coke. He found no traces of chlorides of either copper or zinc in any of the deposits.   On reference to page 193, the soluble matter consisted of chloride and sulphate of lime.   He apologised for not having given the analysis desired.   He had brought the following figures with him :—

									Per Cent.
Copper	.	.	.	.	.	.	.	.	70·65
Zinc .	.	.	.	.	.	.	.	.	28·65
Iron .	.	.	.	.	.	.	.	.	0·56
Lead .	.	.	.	.	.	.	.	.	0·20

The next criticism had reference to the abrasion of the tubes by clinker, a cause of erosion referred to by the President.   In this particular case of breakdown that point was investigated very thoroughly.   He understood that previous breakdowns occurred before the new water supply was used, and that troubles had been experienced due to erosion by clinker and ash in the past.   In consequence, strict orders had been given that the blast and stoking arrangements were to be conducted in a definite manner.   The result had been an end to breakdowns of tubes from this cause.   Orders were also given that the fires should be drawn every evening, which answered another criticism made.   He believed he had given the total sulphur.   With regard to the theories of breakdown advanced by the speakers, he would prefer to answer those, if he might do so, in writing, because there were some important points connected therewith to which he would like to refer.

COMMUNICATIONS.

Mr. G. D. BENGOUGH, M.A. (Liverpool), wrote that on p. 188 of his paper the author stated "the tube had not been burnt, *i.e.* overheated and oxidised, as cupric and zinc oxide were absent in the scale and

salts." A little further up, on the same page, he admitted the presence of cuprous oxide in the scale as usual. The degree of oxidation of the scale, therefore, was there regarded as a crucial test for "burning." He (Mr. Bengough) was by no means sure that that could be admitted, especially in the presence of the reducing gases which occurred in the combustion products of locomotive fire-boxes.

On p. 189 the author stated that the crystals embraced intrusions of cuprous oxide. That, to his mind, might very possibly constitute evidence of burning, but without seeing the structure under the microscope it was impossible to speak definitely. He was sorry that the author had not illustrated his paper by means of photo-micrographs, which would have enhanced its value considerably.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), wrote, in reply, that Dr. W. Rosenhain's criticisms, in so far as they applied to the subject-matter of his paper, viz. boiler tubes—in contradistinction to condenser tubes, which, as the President had pointed out, are absolutely distinct—might be met by the fact that, prior to the use of untreated Birmingham water as supplied under their Welsh Water Scheme, the average life of the boiler tube supplied by the same makers as the specimens examined by him was between three and four years. As soon as the Welsh water was used as feed-water the average life was reduced to a period varying from eight to twelve months. Evidently, therefore, the quality of the water—collected from a peaty upland surface—had a marked effect upon the tubes. The analysis of the deposit indicates this. As to the insulating character of the film of deposit, his attention was drawn thereto by a past experience in the behaviour of heated tubes through which dilute soap solutions were conveyed. He ventured to submit that the low heat conductivity of the film produced by the decomposition of soluble silica or silicates, and possibly of soaps of lime and magnesia, had caused the overheating and subsequent breakdown of the tube. As the author's object was to investigate the cause of breakdown, he did not think it advisable to examine the microstructure of tubes which had not actually burst. Further, the unaffected tubes were not removed from the boilers. Professor Turner's and also Mr. Klein's references to chlorides, he believed, were met by the fact that coke was the fuel used, and that chlorides were practically absent in the deposits inside and outside the tube examined by him (Mr. Vaughan Hughes). With regard to the abrading effect of particles of coke or clinker, that possible cause of injury to the tubes was examined by experienced locomotive engineers before the tubes were submitted to him. The engineers came to the conclusion that the failures could not be attributed to that cause, particularly as the same make of tubes in the same boilers working under improved conditions as to use of blast, &c., had a much longer life when the old feed-water was used than with the new feed-water described above. Mr. A. L. Heathcote's reference in this connection was confirmatory. To Professor Huntington's valued suggestions, he could only reply by stating that the makers of these burst tubes were very "modern" in their procedure, and, he believed, took

great care in specially constructed furnaces, with pyrometer equipments, to ensure even annealing. Further, the difference in behaviour of the same make of tubes under different feed-water conditions was at least suggestive of the annealing conditions over a number of years being approximately equal. Mr. G. D. Bengough's criticisms were chiefly answered by the statements he made above. The method of manufacture of land locomotive boiler tubes precludes the possibility of slag inclusions acting in the manner described. Besides, the shape of the fractures themselves indicated a different cause. He was in agreement with Mr. Bengough if he would allow that the breakdown occurred when the thinned walls of the tubes failed to carry the heat of the furnace gases, and, being covered by a lagging of highly non-conductive material, reached a temperature of 800° or over, as a result of which they collapsed and burst inwards. In the case under consideration it was suggestive that grain structure of parts of the tube removed from the seat of fracture were about normal, although they had been heated at a low temperature for a considerable period of time identical with the part which burst. He was obliged to Mr. Bengough for his allusion to what on first sight appeared to be a contradiction, namely, cupric and zinc oxides on the tubes. He believed it to be generally understood that when a boiler tube was " burnt," it had been heated out of contact with the water in the boiler. That sometimes occurred through oversight and other causes, generally ending in disaster. He submitted that cuprous oxide could be present as the result of reduced copper salts on the inside of the tube. It was known to penetrate copper and its alloys by solid diffusion. It certainly embraced the larger crystals at the seat of breakdown. The President's valued criticisms were very apropos. Had there been no previous history of the same make of boiler tubes in the same locomotives, working under same conditions, with the same fuel plus extra precaution as to the use of blast, proving a " life " of from three to four years, but of only eight to twelve months with the new feed-water, he would cordially agree with him. But those unpleasant variants had been eliminated on a practical scale in this case. Hence he felt sure Sir Gerard would agree that the cause assigned by him (Mr. Vaughan Hughes) for those particular breakdowns was, if not " the whole truth," very nearly approaching that legal exactitude.

NOTES ON A SUGGESTED RECORD OF ANALYSES

By C. A. KLEIN.

IN November last I wrote to the Secretary of the Institute as follows :—

" At the present time there is no standard English reference book for analyses of metals, and in view of the fact that many manufacturers have to carry out detailed analyses, I would suggest that a certain space be reserved in the Journal for analyses of raw and refined metal sold or bought during the previous year.   This would provide a convenient reference for members who require information with regard to the purity of raw and refined metals, *e.g.* copper, lead, zinc, &c., and after a time would become a record of any changes in the purity of such metals."

This letter was laid before the Publication Committee, and I was then invited to write a short paper dealing with the above suggestion, in order that the opinion of other members might be obtained upon the question.

The desirability of such a reference has often been impressed upon me when I have required a general idea of the standard purity which is commercially possible in metals.   At the present time, the only course open is to search text-books, journals, &c., and as a general rule the search is rewarded by the discovery of analyses some years old—failing this, a series of analyses must be made ; this latter course is the most frequent, and is often tedious and expensive.   It is well known that certain brands of metal are of greater purity than others, although little or no difference in price is obtained, and therefore to certain manufacturers who require the purer brands, such a reference book would be of great value in deciding their choice.

Further, for certain purposes some particular impurity is fatal, whilst others are not of great importance, and it frequently happens that only some brands are known to be free from such injurious impurities, although their total impurities may exceed those contained in the undesirable brand. These differences are often due to local conditions. I am strongly of opinion that such a record of analyses is capable of universal application, and that, if generally applied, it would result in a most reliable work of reference.

It is my intention to give only the merest outline of the suggestion, in the hope that discussion will shape the idea into a workable scheme.

I suggest that members who have carried out analyses during the previous year be invited to forward to the Institute copies of such analyses as they deem desirable for publication, and that the Journal be made to contain a summary of these figures. A suggested summary is appended.

There are many points which require to be considered prior to the adoption of such a scheme, amongst which I must mention the following :—

(1) Is the naming of brands desirable, or would it be preferable to average the whole of the figures?

(2) The analyses ought to be expressed in a standard manner, and be beyond question as to accuracy.

(3) Would it not be desirable to appoint an editor or subcommittee for each metal, who shall be specialists in that particular branch, and who shall present a short report to accompany such analyses?

(4) Is it desirable to publish the names of the members supplying the figures?

I am fully aware that the suggestion is open to considerable criticism, but I am convinced that there is a real need for some reliable record of analyses of non-ferrous metals.

SUGGESTED FORM OF SUMMARY.

Lead during Year 1909.

Per Cent.	English Refined.				Australian Refined.			
	Maximum.	Minimum.	Average in 19 Samples.	No. of Samples in which Average was Exceeded.	Maximum.	Minimum.	Average in 50 Samples.	No. of Samples in which Average was Exceeded.
Silver								
Copper								
Bismuth								
Cadmium								
Arsenic								
Antimony								
Tin								
Aluminium								
Iron								
Zinc								
Manganese								
&c.								

DISCUSSION.

Mr. A. E. SEATON, Member of Council, in opening the discussion, said that he had not previously noticed the paper, but after hearing it read he was very much struck with the suggestions it contained. He thought the idea underlying it was a very good one indeed ; in fact, it was one he had in mind as regards various metals many years ago. In the early 'eighties of last century, when mild steel began to be used freely for ship-building and boiler-making, it occurred to him that engineers ought to have something by which they could define what they meant by "mild steel," and certainly something which they could rely on if they were called upon, as they so frequently were then, to supply the "*best* mild steel." What was the *best* mild steel, and how was he to arrive at a method of ascertaining whether the steel he was buying was the best steel or not? He sent round to about eight or ten of the most important steel makers in the kingdom for such an ideal analysis, such as they considered to justify the title of *best mild Siemens open-hearth steel*. It was in the days before basic steel, and they were all good enough to send him what might be called a standard analysis of acid steel. They differed very considerably, although of course only fractionally, because the amount of phosphorus and sulphur that would be permitted in such a material was naturally very small. He was surprised, however, to find how the makers at that date differed from one another in what might be called the relative quantities of the various ingredients, especially as to carbon and manganese. If the author's suggestion was carried out, he, as an engineer, would be only too delighted, because in buying copper it was not easy, if a dispute arose with a copper merchant, to say whether the material sold as "best selected" was entitled to that designation, and still less so with many of the other metals. For instance, it was not an uncommon thing in the galvanising business to obtain a zinc which on analysis was found to contain lead, and which did not give satisfactory results. It was not easy for an ordinary, everyday engineer to feel satisfied with the assurance of the seller of that zinc that it was quite up to the description of best Silesian zinc, for example. An engineer generally had recourse then to a text-book—probably it was an old one, as it was an engineer's—and he had to swallow what was contained therein, and feel very dissatisfied with it. In no case, however, could any statement made in a text-book have the authority as that made by the Institute of Metals would have. He was not a member of the particular committee referred to in the paper, but he did think the subject which had been raised was very well worthy of serious consideration.

Mr. G. A. BOEDDICKER, Member of Council, thought the author's suggestion was a very good one from a general point of view, but there were several great difficulties in the way. Taking the four points specifically mentioned. In the first place, he was decidedly opposed to the naming of brands if the analyses were given, because this might lead

to advertising certain brands, and that was one of the things the Institute had to guard against. The second suggestion presented great difficulties. The author stated that " The analyses ought to be expressed in a standard manner, and be beyond question as to accuracy." But who was to be judge of that? A curious circumstance happened to him a short time ago illustrating that difficulty. A quantity of nickel was delivered, the assay of which gave 98·78 per cent. The user of the nickel, who used it for nickel-steel, had it analysed, and his analyst found only 94 per cent. On reference the former result was confirmed. Now supposing the lower result had been sent in for publication, this would have given a very extraordinary impression of the purity of nickel at the present time. There existed only very few standard methods, and the number of analysts whose results would be accepted as beyond question of accuracy was very limited. With regard to the third suggestion made by the author, namely, " Would it not be desirable to appoint an editor or sub-committee for each metal who shall be specialists in that particular branch, and who shall present a short report to accompany such analyses?" he wished to point out that a specialist in a particular branch would generally be interested in the manufacture of the metal in question, and he did not think competitors would be very anxious to send him analysis to criticise. In the fourth place, the author asked, " Is it desirable to publish the names of the members supplying the figures?" In his opinion that would be absolutely necessary, as an analyses would be quite valueless without that guarantee. There could be no doubt it was very desirable that the whole subject should be considered thoroughly. Not only the text-books used by engineers, which, as Mr. Seaton stated, were generally of ancient date, but even some of the very latest text-books contained some most extraordinary analyses, which were simply copied from older books, and did not at all give a true record of the great strides which had been made in raising the quality of most metals.

Mr. H. J. Humphries (London) suggested that the publication of all sorts of analyses without giving the names of the brands would be of comparatively little value. To say, for instance, that they were simply an average of nineteen English brands or an average of fifty Australian brands would not carry members very much further than where they were before. From his own experience, he had found as large a difference as 3 per cent. between two brands of English tin, which was a very important point, considering that the value of 3 per cent. of tin at the present day was about £4, 5s. per ton. On the other hand, the publication by a society or by individuals of an alleged analysis of a certain brand might possibly lead to complications in the law courts, unless the second suggestion the author had made was carefully thought out, namely, that the accuracy of the analyses published was beyond dispute. Probably it would be necessary for a committee of the Society to see that that was the case, and to fix, it might be, a standard method of analysis. It was a well-known fact that somewhat divergent results might be obtained from alternative methods which were at present used

for arriving at the results. With regard to the question of the desirability of publishing the names of those who vouched for the accuracy of the figures published, he thought that would be absolutely necessary. As a concluding suggestion, he desired to ask, Would it be beyond the province of the Institute to retain a referee, whose word would be accepted by both parties—on the one hand the producers of the brands, and on the other hand the manufacturers who were using that class of metal?

Mr. A. Philip, B.Sc. (Portsmouth), wished to endorse the favourable opinion expressed by Mr. Seaton and the other speakers on the author's proposals. It appeared to him to be one of very great importance and also of great practicability even in spite of the difficulties which Mr. Boeddicker had pointed out, and which were undoubtedly very real.

Manufacturers were not infrequently called upon to manufacture alloys to stringent specifications drawn up for special reasons by metallurgists, physicists, and engineers, and sometimes could not readily decide as to whether the material for preparing such alloys were to be obtained in the open market or not, nor what their cost might be. For instance, sometimes the use of zinc containing remarkably low proportions of lead or of cadmium was required. In the case of the latter element he understood that very minute proportions exert an extraordinarily prejudicial effect on the drawing of brass containing it into thin articles, such as cartridge cases, &c. Whilst in Sweden in 1908, a manufacturer of electric smelted zinc which was claimed to be quite free from cadmium informed him that as little as 0.01 to 0.02 per cent. of cadmium had a most serious effect in drawing brass for such purposes. The ordinary zinc of commerce contained in his experience very varying proportions of cadmium. As much certainly as 2 per cent. was not at all uncommon. He had found that manufacturers who wished to go into the manufacture of zinc alloys, free from lead and cadmium, did not know where to obtain the necessary materials; and in such a case, and in many similar situations which must occur to the minds of many of those present, a scheme such as the author proposed, if carried out under suitable precautions, should prove most useful.

If the principle of the author's suggestion was accepted by the Council of the Society, it would be possible for an individual to send forward a statement that zinc or any other metal could be purchased entirely free from certain deleterious elements, or, at any rate, in which these elements did not exceed a specified maximum. Such a statement could be published together with the current price if the Council were satisfied of its general probability, but without the name of the manufacturer or the brand of metal being stated. A manufacturer being thus rendered aware that the material he required was a commercial article and financially satisfactory, could ascertain where it was to be obtained by suitably advertising for it.

The President requested the author to be good enough to send in his reply in writing, as there was not time for him to give it before the conclusion of the meeting.

COMMUNICATIONS.

Dr. G. H. BAILEY (Kinlochleven, N.B.) wrote that he regarded Mr. Klein's suggestion as a most useful one.

Whilst there was to be raised against it some objections in points of detail, the information would be most valuable, and in its broad lines the compilation of such results as he (Mr. Klein) asked for should not offer any insurmountable difficulty.

He thought, however, that every endeavour should be made to avoid unessential detail. Whatever it might be thought proper to publish later by way of extension, simplicity and clearness of statement should, he thought, be aimed at first.

Essentially, in his opinion, there should appear the recognised impurities that are regularly determined in the metal for commerce, and incidentally reference might be made to commonly occurring impurities. In certain branches where custom had established well-recognised brands or where market limits of purity were imposed, those might usefully be stated.

Mr. C. O. BANNISTER, Assoc.R.S.M. (London), wrote that he considered Mr. Klein's suggestion excellent, and that the information so collected would be very valuable to all interested in the metallurgy of non-ferrous metals and specially useful to lecturers and writers on metallurgical subjects, to whom all others interested in the industry had to look at some time or other for information. The exact manner of obtaining, selecting, and publishing would undoubtedly be a matter of some delicacy, as it would not be difficult to give reason for disputes which might cause anxiety to those most responsible for the welfare of the Institute. In the use of the word "Brand," it must be remembered that although a brand might be a guarantee that a metal was suitable for certain purposes, it did not necessarily follow that the analysis of a branded metal would always be the same. The writer suggested as a safe course for, at any rate, the commencement of the collection of analyses, that only published results be used, and that the members at present engaged on preparing abstracts for the Journal be instructed to keep details of all analyses of metals and alloys separate for tabulation in the Journal. It might be possible at the same time to collect all reliable information on the physical constants of metals from which an up-to-date table could be drawn up and published from time to time.

Mr. A. J. DREYDEL (London) wrote suggesting that where possible and likely to be of interest, a determination of certain physical properties, such as elasticity, breaking strain, and electrical conductivity, should be added to the results of analysis of the sample.

In view of the growing modern deposition of "rare" metals from their position of rarity, he (the writer) should like to put in a plea for the inclusion in the proposed schedule of metals of comparatively slight or even no present industrial value. In support of that might be

instanced the recent industrial adoption of metals such as tantalum and tungsten by the electric lamp manufacturer and the steel maker. Here, as in many other cases, chemical and physical considerations went hand in hand. The possession of the suggested data in the early or even pre-industrial history of such metals would, he believed, be of more than merely scientific interest.

Though, perhaps, outside the scope of the Institute of Metals, he should like to express the hope that Mr. Klein's admirable idea might be the precursor of some standard work of reference in which the chemical analysis and physical characteristics, not alone of the metals, but also of the principal alloys, commercial chemicals, might be periodically recorded.

Mr. H. L. HEATHCOTE, B.Sc. (Coventry), wrote that he was much interested in the scheme brought forward by Mr. C. A. Klein, and thought that a sincere attempt ought to be made to overcome the difficulties attendant on carrying out the suggested publication of analyses. If it could be carried into effect, the value of the Journal to the younger analytical and metallurgical chemists would be much enhanced, and should increase the membership of the Institute. The objections to naming the brands might, perhaps, be met by specifying the articles and purpose for which material having the given analysis was suitable.

He thought a committee should be appointed capable of weighing the numerous issues and evolving some recommendations for carrying out the proposal.

Dr. R. SELIGMAN (London) wrote that he would like to give his cordial support to the excellent suggestion which Mr. Klein had made. With regard to the questions which Mr. Klein raised, it seemed essential to him (the writer) that the brands should be named. If this were not done the information collected under Mr. Klein's scheme would be valueless. Whilst it was not desirable that the Journal of the Institute should be used for advertising purposes, there could be no harm in making it a source of information, which, if accurate, would be most valuable to the members.

Mr. Boeddicker's objection to the suggestion of entrusting this work to specialists for each metal, that those specialists must necessarily be biassed, would not apply if specialists were chosen who were not connected with the producers of the metal in question.

It was impossible to guarantee the accuracy of any analysis, but the difficulty could be avoided if the name of the analyst, and in difficult cases the method he used, were given. Those desiring the information could then judge for themselves of the value of the analyses.

Mr. C. A. KLEIN wrote, in reply, that he was pleased to note that all members who had discussed the suggestion had approved the general plan, though they differed as to the extent of its possible application. In view of that difference of opinion, he would suggest that a committee be

formed to consider the proposal, together with the criticisms and reply, with a view to giving effect to the suggestion or any modifications which might be deemed advisable.

With regard to the various criticisms, he wished to thank the authors for their contributions, as his sole idea was to give only the merest outline of a suggestion in the hope that discussion would shape the idea into a workable scheme.

He must endorse the statements of Messrs. Seaton and Boeddicker as to the ancient and much copied analyses usually found in text-books, and regretted that he could not share Mr. Bannister's opinion as to the value of the tabulation of already published results because of the scarcity of such results, and, further, because no Society could be more authoritative than the Institute, seeing that its members comprised such a variety of workers engaged in the metal industries. The objections raised by Mr. Humphries to the quotation of average figures was a real one, but the writer had attempted to overcome the difficulty by giving maximum and minimum values, together with a statement of the number of samples in which the average value was exceeded.

The question of advertisement which arose in connection with the naming of brands was covered admirably by the suggestion of Mr. A. Philip.

Dr. Seligman's criticism with regard to the bias of a specialist was, he believed, a correct one, and he did not think any trouble need be anticipated on this point.

Whilst agreeing with Mr. Boeddicker as to the difficulty of always obtaining accurate analyses, he (Mr. Klein) was of opinion that the question was by no means as serious as might be indicated by the example quoted. A large number of products were sold to specification, and though at times differences in analyses arose, the differences were not, in his experience, frequent enough to affect the value of the suggestion, provided, of course, that care were taken in the selection of analyses by a competent committee.

He desired to express his cordial agreement with Mr. Dreydel as to the inclusion of the now so-called "rare" metals, in view of the possible advent of these as metals of industrial importance.

Dr. Bailey's suggestion of simplicity and clearness of statement was of the greatest importance, and he considered that it should be the guiding principle for any ultimate scheme.

The author was strongly of the opinion that the form of summary already suggested, together with an additional summary for the tabulation of analyses of metals stated to be suited for particular purposes, would make an excellent start, and be capable of expansion when and if experience indicated the proper lines. The publication of physical properties was not contemplated when the suggestion was made, as he anticipated that complications might ensue. The question was well worthy of consideration.

He sincerely hoped that a scheme would be evolved, and would lead to the publication by other Societies of a periodic record of the analyses of chemical products in general.

THE USE OF CARBONACEOUS FILTERS IN THE SMELTING OF ZINC, AS EMPLOYED IN THE HOPKINS FUMELESS ZINC PROCESS

By C. O. BANNISTER, A.R.S.M., M.I.M.M.

THE process described in this paper is the outcome of experiments commenced by the Rev. Evan H. Hopkins some ten years ago.

These experiments were begun with the object of obtaining zinc free from lead as a product when smelting zinc materials containing lead.

In the first experiments a mixture of zinc oxide, lead oxide, and carbon was placed in a cavity in a carbon block
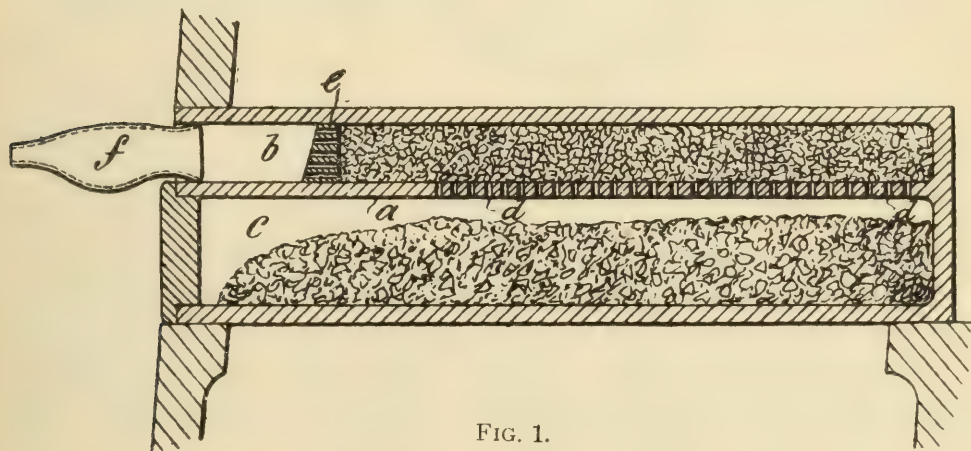
FIG. 1.

fitted with a carbon lid; the carbon block was then introduced into a muffle, and the zinc was distilled over into a receiver. As the result of the experiment, zinc practically free from lead was obtained, and the lead was found in a lump inside the carbon block.

The first idea as to the method of applying this principle on the large scale was to use a modified retort such as that shown in Fig. 1, and to pass the products of distillation

through an incandescent filter of carbon. In the figure given, the retort is shown to be divided into two portions by means of a partition (*a*) made of clay, and perforated with small holes (*d*).

The upper chamber (*b*) was filled with fine lumps of charcoal or coke, well pressed together, and kept from falling apart by means of a movable and perforated stopper (*e*). After the ore mixture had been placed in the chamber (*c*), this portion was closed and luted. During the process the
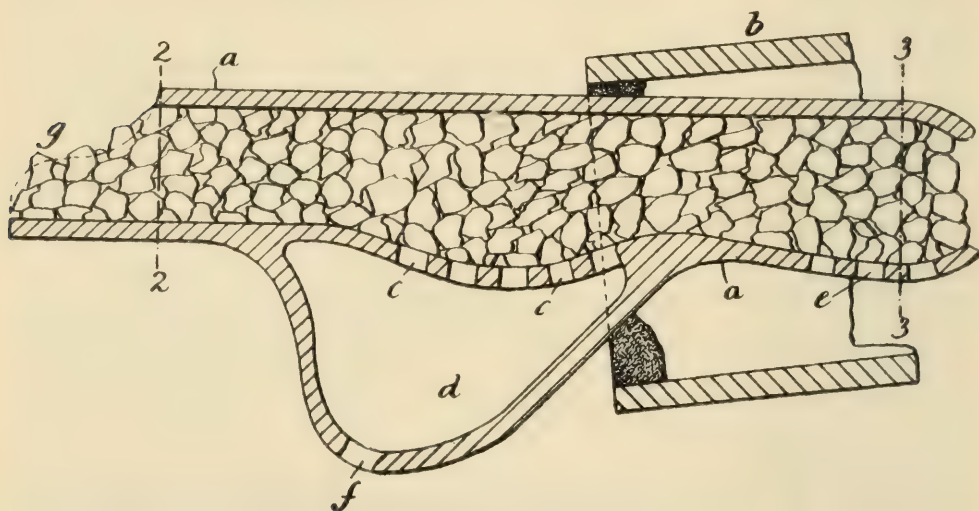
Fig. 2.

zinc distilled through the carbonaceous filter, and was condensed and collected in the receiver (*f*) in the ordinary way.

From the commencement it was evident that in order to make this process a commercial success it would require considerable modification and simplification, and experiments were carried out with a view of making the condenser also take the part of filter. After a large number of experiments the form shown in Fig. 2 was adopted. This, as will be seen on reference to the figure, consisted of a large condensing chamber divided by means of a perforated partition into a condenser proper and a receiver (*d*).

The upper portion or condenser proper was filled with small pieces of carbon in the form of charcoal or coke, and the whole was placed sufficiently far into the zinc retorts to insure that the carbon filter should attain a sufficient

temperature to prevent choking. This form of condenser was modified slightly from time to time, and was used in actual practice, the results obtained being compared with those obtained from retorts fitted with the ordinary condenser. The experiments were made with much care, particular attention being paid to weight, charge, analyses, &c., and the whole operation was watched for twenty-four hours without intermission.

During these experiments, which were made in furnaces treating galvaniser's dross, the following points were clearly brought out:—

1. The zinc obtained from the Hopkins condensers was invariably purer and freer from lead.
2. No oxide or zinc fumes emanated from the Hopkins condensers.
3. The zinc flame, always observable at the mouth of ordinary condensers, was absent when the Hopkins condensers were used.
4. By the use of the Hopkins condensers a larger proportion of the spelter contained in the charge was obtained as metal.
5. It was established that the hotter the furnace the greater was the yield of metal by the Hopkins condensers, whereas with the ordinary condensers higher temperature means increased zinc flame, fumes, and loss.

It will thus be seen that the above series of trials was most fruitful in indicating the practicability of preventing the zinc fumes which are always a cause of annoyance in the neighbourhood of zinc works, and at the same time the prospect of obtaining thereby a greater yield of zinc.

It was, however, considered still possible to simplify the construction of the condenser so as to make it much cheaper. To this end the whole of the central portion of the condenser (Fig. 2) was eliminated, but exactly the same principle was retained in the new arrangement.* In this case the condenser (B), as ordinarily used in spelter works, or a slightly modified

* It has been pointed out to the author that this portion might be interpreted as a claim to a certain form of inner sleeve on which a certain firm has a patent, but he need hardly say that it was not his intention to raise any question on this patent.

form thereof, may be used, into which is inserted, at the inner end, a carbonaceous filter to keep back the lead, and, at the outer end, a tube (C), packed with carbon.   This combined form is to be used when the aim is to obtain a high quality zinc as well as the subsequently mentioned advantages, but when it is desired merely to eliminate the objectionable fumes
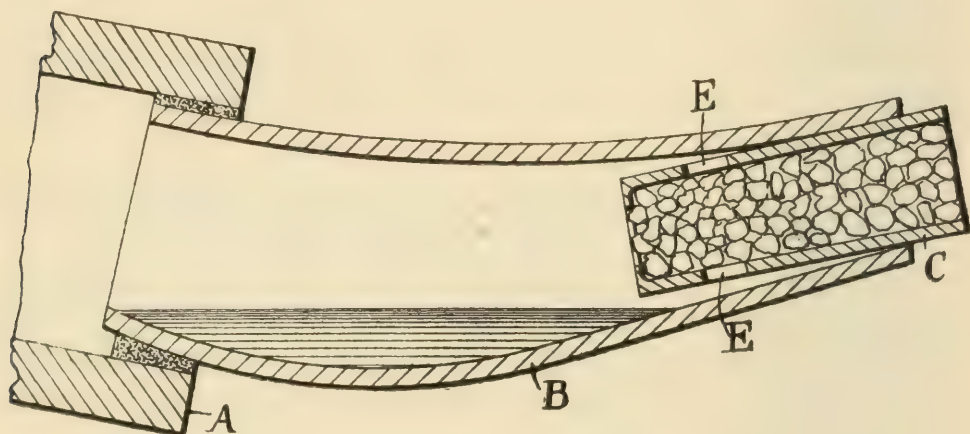
Fig. 3.

and to obtain a higher extraction, the outer tube only need be used, as indicated in Fig. 3.

Various forms of fire-clay tubes have been employed to contain the carbonaceous filter; to illustrate one of these
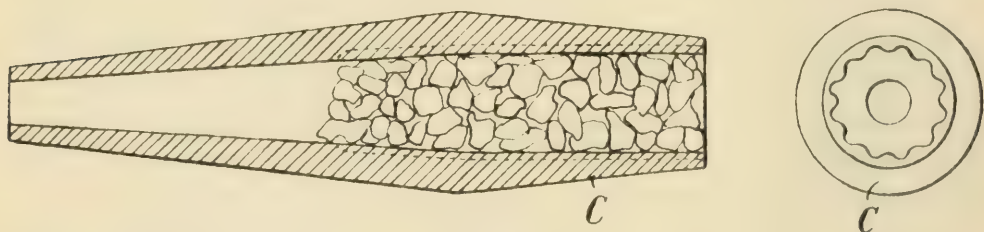
Fig. 4.

Fig. 4 is given, which shows a double conical tube, having one end, namely, that which enters the condenser, made with longitudinal corrugations internally.   By reason of these corrugations the choking of the tube is prevented during work, but the escaping gases, &c., come into contact with the hot carbon.   The tube at present in use consists of a cylinder

about 8 inches long, $3\frac{1}{2}$ inches external diameter, and 2 inches
internal diameter, and has flanges to keep in the coke; it also
has a small hole running through its wall for the insertion
of a pricker when found necessary during the process.

It will be seen from the foregoing that the process,
beginning with the object of making lead-free spelter only,
has been gradually modified and simplified, and in its present
form embraces the three following objects :—

    (*a*) Manufacture of pure spelter.
    (*b*) Prevention or reduction of zinc fume.
    (*c*) Obtainment of higher yields.

(*a*) MANUFACTURE OF PURE SPELTER.

Since Mr. Hopkins first demonstrated the possibility of
obtaining pure zinc by passing the vapours from zinc retorts
through incandescent carbon this process has received con-
siderable attention from zinc smelters, and it is now an
accepted fact that the operation may be carried out economi-
cally and effectively.

To what extent the process will be applied to ordinary zinc
smelting is at present unknown, as the demand for zinc of a
very high standard of purity is somewhat limited ; but there is
no doubt that it will be adopted in the treatment of materials
containing too much lead for the production of commercial
spelter direct, that is, without a subsequent refining operation.

The fact that a carbonaceous filter behaves as a strong
reducing agent puts it far in front of filters composed of
materials which do not possess this property, for its presence
in an incandescent state insures that the whole of the metallic
vapours shall be and remain reduced, and at the same time
any carbon dioxide passing out with the gases will be reduced
to carbon monoxide.

As the amount of reduction that takes place in the filter
requires only a little carbon, the consumption of the carbon of
the filter is small ; but this consumption is advantageous, as it
tends to keep open the filter and lessen pressure due to the
deposition of lead, &c.

In actual working, coke has proved more suitable than coal for the filter, and at the same time it is more economical. In fact, experiments have demonstrated that coke is the best material for this purpose, and it should be of a light porous variety, not dense, and should contain only a small quantity of volatile matter.

As to the results obtained, the following illustrates the purity of the zinc :—

From galvaniser's dross the spelter contained 99·86 per cent. zinc from the Hopkins filter as compared with 98·75 from an ordinary condenser working on the same charge.

As to whether the process will be used to any extent for the treatment of zinc-lead concentrates time alone will decide, for details other than the production of pure zinc have here to be taken into account, such as the manner in which the charge attacks the retorts, &c. For rich zinc concentrates containing smaller quantities of lead, however, there is no doubt that the process is most suitable, as not only can pure zinc be obtained, but a considerable quantity of the lead can be recovered on treatment of the filters.

Some comparative tests have been carried out on the treatment of Broken Hill middlings, and not only was a purer zinc obtained from the Hopkins filters, containing 99·6 per cent. zinc as compared with 96·5 from ordinary condensers, but the yield of metal averaged over 20 per cent. more when such filters were used.

(b) Prevention of Zinc Fume.

In view of the necessity for some cheap, simple, and effective method for preventing the formation or reducing the amount of fume during zinc smelting, the Hopkins outer cork is of very great importance, for it is found to be most efficient as a fume preventer.

The presence of this cork or nozzle, packed with carbon, acts in almost a magical manner, keeps back practically all trace of zinc fume, and gives to the gas burning at the ends of the nozzles a flame similar to that obtained during the burning of carbon monoxide gas. The inspection of a zinc furnace

fitted partly with ordinary condensers and partly with Hopkins condensers is most surprising and instructive, and the absolute efficiency of the nozzles as now used is at once clearly demonstrated. The presence of the hot carbon at the outside end of the condenser or pipe seems to affect the whole condition of the condenser, for even when put in so loosely that part of the flame escapes between the carbon-containing nozzle and the mouth of the condenser, this flame also is practically free from zinc. From the time the gas in the coal finishes until the last tap, the whole condition of the furnaces supplied with nozzles is improved.

During the periods of tapping the zinc the fumes are very much less, for only two or three condensers are uncovered at a time, and as tapping proceeds the nozzles as removed are put into the condensers already tapped. The workmen also notice further advantages, for the metal in the condensers fitted with nozzles is hotter than the metal in ordinary condensers and will more readily melt up " drippings " of spelter ; also skulls of metal are never present in the condensers.

The Local Government Board have taken great interest in all methods suggested for the prevention of the escape of zinc fume, and four Government Inspectors have examined the Hopkins process in operation in Swansea, and were much impressed by what they saw. The following are extracts from the Annual Report on Alkali, &c., Works, 1908 :—

Page 90.—" In a previous report (42nd, p. 64) I have mentioned that trials were being given to the Hopkins nozzle, one of the variants of this type of appliance, and with some amount of success. The results of trial have led to simplification in design and construction without, I am informed, any sacrifice of efficiency. It is now believed that not only can spelter be obtained of greater purity, but also in substantially increased yield as compared with other retorts working under the same conditions of raw material, &c., in the ordinary way without the nozzle. If working for quality, *i.e.* freedom from lead, the vapours from the retort pass through an additional incandescent chemical filter suitably formed in the furnace end of the condenser. At the outer end of this condenser another appliance aims at reducing any zinc oxide formed in the condenser from access of air to the vapour of zinc. From recent observation of two contiguous benches of thirteen retorts each and comparison of the escaping gases near the time of first tapping, *i.e.* at the period of the greatest liability to

evolution of fume, I am convinced of the possibility of success in preventing this in very great measure. It was easy to compare the fume escaping from similar benches not provided with the nozzle, and in the same condition as to charge, &c."

Page 180.—"Several experimental efforts are at present being made to reduce the impalpable white cloud of oxide of zinc which escapes from the retorts during the smelting operation.

" The ' Hopkins Condenser ' is being tried at Swansea with encouraging results. The condenser, which is provided with what may be called a chemical cork, consisting of coke, is adapted to the retort or pot commonly in use.

" By this means the inventor endeavours to prevent the formation of zinc oxide during distillation, thereby obviating the escape of the metal as an oxide seen in the familiar white fumes inseparably associated with the manufacture of spelter or commercial zinc. At the works referred to, these condensers showed a remarkable diminution in the escape of fumes, and we are informed that there is a substantially increased yield of metal as compared with that obtained by the ordinary process of smelting."

(*c*) Obtainment of Higher Yields.

The absence of fumes which is noticed when the Hopkins nozzles are in use on zinc retorts should naturally lead to less loss by oxidation and therefore to higher yields of metal.

This has proved to be the case when the process is worked under proper conditions, and the results of continued comparative tests have always shown the Hopkins nozzles to yield more metal. It must be remembered, however, that in the extraction of zinc many factors must be considered which are likely to upset results, such as the breaking of retorts, unequal heating of the furnace, &c. The first comparative tests for yield were carried out on contiguous bays of thirteen retorts, in a two-tiered, gas-fired zinc furnace; further bays of thirteen retorts were added until the whole of one side of the furnace was worked against the whole of the other side.

As the charges in all cases are absolutely similar, only the weight of metal actually obtained need be taken into account.

Table I. shows the results of eighteen weeks' continuous work, and it will be noticed that during this run only one week showed a decrease in the amount of spelter yielded by the Hopkins nozzles.

TABLE I.—*Results of First Extended Series of Tests.*

Date.	Ordinary.		Hopkins.		Increase by Hopkins.
	Average Number of Pipes used each Day.	Average Yield per Pipe per Day.	Average Number of Pipes used each Day.	Average Yield per Pipe per Day.	
Week ending		Lbs.		Lbs	Per Cent.
Oct. 12 . .	143	20·88	13	21·90	4·9
,, 19 . .	143	20·43	13	22·25	8·9
,, 26 . .	143	20·00	13	21·80	9·0
Nov. 2 . .	130	20·20	11	22·60	12·0
,, 9 . .	140	21·26	13	22·94	7·9
,, 16 . .	141	22·10	13	23·30	5·4
,, 23 . .	135	20·00	18	22·60	13·0
,, 30 . .	129	20·20	26	19·00	−6·3
Dec. 7 . .	132	19·20	23	19·70	2·6
,, 14 . .	130	19·20	25	20·40	6·2
,, 21 . .	129	19·13	25	20·60	7·7
,, 28 . .	125	20·90	24	21·16	1·2
Jan. 4 . .	125	20·80	24	22·40	7·7
,, 11 . .	129	18·20	26	19·20	5·5
,, 18 . .	129	16·10	26	18·20	13·0
,, 25 . .	128	15·91	25	17·70	11·2
Feb. 1 . .	127	16·87	25	18·68	10·7
,, 8 . .	116	17·54	38	18·85	7·5

Table II. shows the results of the first week's work on a recently repaired furnace, one side being worked against the other.

TABLE II.—*Details of Recent Week's Work.*

Date.	Ordinary.					Hopkins.					Increase by Hopkins.
	No. of Pipes.	Yield.			Average Yield per Pipe.	No. of Pipes.	Yield.			Average Yield per Pipe.	
		Cwts.	Qrs.	Lbs.	Lbs.		Cwts.	Qrs.	Lbs.	Lbs.	Per Cent.
Oct. 7	75	11	2	25	17·51	75	12	0	21	18·20	3·9
,, 8	75	10	1	14	15·49	75	11	2	21	17·45	12·6
,, 9	78	11	1	16	16·36	75	12	3	6	19·12	16·9
,, 10	78	10	3	26	15·77	78	12	0	17	17·45	10·6
,, 11	78	13	0	25	18·98	78	13	2	0	19·25	1·4
,, 12	78	11	2	1	16·52	74	13	0	6	19·62	18·7
,, 13	78	13	1	16	19·23	75	12	1	10	18·43	−4·1

It must be remembered that in the ordinary method of working the zinc furnace the yields vary very considerably from day to day in different furnaces and even in the two sides of one furnace, therefore it is to be expected that occasionally for one day, or even in the case of the average for a week, the yield should apparently be less when the condensers are used.   On examination of the tables given it will be noticed that there is not only a distinct advantage from the point of view of yield, but also that the percentage variation and the greatest deviation from the mean result are less with the Hopkins nozzles, points which are both in favour of this method.

Cost.

It is estimated that the corks or nozzles will be made at a cost of 4s. to 5s. per 100, and that filling for a furnace of 150 retorts will cost 2s. to 2s. 6d. per day.

Summary.

1. By means of the Hopkins carbonaceous filters and corks or nozzles the following three advantages may be obtained in zinc smelting :—

> (*a*) Pure spelter.
> (*b*) No zinc fume.
> (*c*) Higher yield.

2. The process may be applied to any already existing retort zinc furnace, no constructive alterations being necessary.

3. Only a slight modification of the condenser is necessary, this consisting of the widening of its mouth.

4. The process is absolutely simple to work.

5. The metal is hotter in the condenser and no skulls of solid zinc are formed.

6. Not only is a higher yield obtained but also a more steady yield, less fluctuation taking place when the nozzles are in use.

DISCUSSION.

Mr. H. M. RIDGE (London) said there were a few points he wished to raise in connection with the paper, the first being a formal one. He noticed the paper was headed a " Fumeless Zinc Process." The production of zinc was really more of an apothecaries' job than anything else. It consisted of an endless number of minute operations, each one of which had to be carried out carefully in order to prevent disaster. The method which the author advocated was only a detail in that connection ; he did not think it could really be called a separate zinc process ; it was really a variation in the method of condensation. The paper dealt with two filters, which he would like to separate, and call the inside filter and the outside filter. Dealing with the outside filter first, the author claimed that it gave an increased yield of zinc, or, in other words, an increased recovery of spelter. A good deal depended on how the furnaces were worked. It was fairly difficult to prevent an occasional cooling down of the furnace during the distilling operation, and unless there was a reducing atmosphere in the condenser during the whole period, of course some of the zinc, which was either in the form of vapour or already in the form of liquid, was liable to be re-oxidised in consequence of air being sucked into the condenser from outside whenever the temperature went back, and the flow of carbon monoxide gas and zinc vapour from the retort was reduced in quantity, or temporarily stopped altogether. The use of the outside filter would, to some extent, prevent that ; but he was afraid that, although that was very pretty, it was known a good many years ago. He found, on looking up the German Patent Specifications, that Kleeman took out various patents in 1879 and the following years which covered the same thing. He had had a diagram of one of them drawn, which also showed the use of a carbon filter, through which the carbon monoxide and the uncondensed zinc vapour passed, afterwards being burnt at the top. That arrangement had been in use for a good number of years ; and although he was not aware whether it was in use to-day, it certainly was a couple of years ago in at least one work in Upper Silesia. It appeared to him that what the author wished to do with his nozzle was to overcome the difficulties of the condensation of the zinc vapour in an insufficient space. From his own experiments he had found that not only the sectional area of the condenser, but the cubic contents required for efficient condensation of the zinc vapour, should be larger than was usual in Swansea. The furnaces in Upper Silesia use larger condensers, and in the newer furnaces in the Rhenish district larger condensers had been for several years past in successful operation. A further question was the regulation of temperature in the condenser, because, if the temperature of the condenser was a little too high, the zinc was not recovered, but went off uncondensed through the end ; and if it was too low, other troubles were experienced. With the carbon nozzle a certain amount of regulation of the temperature was obtained. On the other hand, if the furnace was going very hot, a point to which the author referred in his paper, and which he said was

liable to entail considerable loss of zinc, he was afraid the difficulty would not be entirely overcome by the use of the outside filter or nozzle, because the condenser was insufficiently large, so that the vapour passed through too quickly, and before it had time to condense. It seemed to him that, no matter what one did with the small Belgian type of condenser, it was impossible to expect to overcome that difficulty satisfactorily. With regard to the use of the inside condenser, he was sorry to see in the paper that the author did not give any details as to how it was to be arranged. Some sketches were shown of what was done in the original experimental stage, but not of what had been done later, or was being done now. Perhaps the author would be able to give some explanation of that afterwards ; if he could do so, it would be of interest. The manufacture of spelter which was very low in lead was of course a desirable object, which he was sure all spelter manufacturers would like to attain, but, on the other hand, there were various points which had to be considered. The manufacturer always wanted to know where the economical limit was situated. He had personally had some experience of the treatment of Broken Hill ores containing an appreciable amount of lead, and had always aimed at distilling as much lead over with the zinc as he possibly could because it did not cost anything. The lead was recovered in a directly saleable form, containing over 99 per cent. of lead out of the molten metal, without remelting as was formerly the case ; this was done by running the metal, when tapping the furnace, direct into a large casting ladle, in which the lead settled at the bottom, so that, from ore, or another product rich in lead, a spelter could be produced in one operation which was directly marketable both for galvanising or for brassmaking, and at the same time a fair amount of lead, which had been distilled over with the zinc, was obtained without further treatment or expense. That brought him to another point. The tonnage of material which remained for re-treatment for recovery of lead was an important item, because of course it had to be smelted sooner or later, and it was desirable to keep down the weight of it as much as possible. If some of the lead was collected in a carbon filter, the carbon filter obviously needed to be re-treated later on for the recovery of the lead, so that there were two materials for that re-treatment—first of all the residue which was in the retort at the end of the distillation period plus the carbon filter ; and although the weight of each filter was small, it added up, and in the long run amounted to an appreciable quantity. In the other case the practice which he had adopted was, that he recovered as much of the lead in the settling ladles as possible. That quantity did not require any further treatment, so that there was only the residue in the zinc retort to be further treated. He thought, however, a point where the arrangement might certainly be of use was in the treatment of zinc iron ores. That was probably known both to Mr. Hopkins and Mr. Bannister. A good many zinc ores and metallurgical products were so high in iron as to cause an appreciable difficulty, and, strange as it might seem, some of the iron appeared to go over into the zinc, so that a bad spelter was obtained. Possibly by the use of a carbon filter, that difficulty might be overcome. He did not know whether that

was the case, because he had not tried it; he simply threw it out as a suggestion. He had one objection to raise to the use of the inside filter, and that was on account of the danger of the filter choking. The retorts which were used for the distillation of zinc were all more or less porous, and it was desirable to reduce the pressure in those retorts as much as possible, otherwise great loss of zinc was caused owing to leakage through the walls, even when using the best materials for making the retorts. Naturally every obstacle put in the way of the flow of the gas from the retort into the condenser tended to increase the pressure. He thought that was a point which should certainly not be overlooked, and he hoped the author would give his opinion on that point also. He noticed that one sketch showed the inside filter projecting a considerable distance into the retort. That was detrimental, because it decreased the cubic capacity of the retort available for the charge. There was a small detail he wished to mention in conclusion. The author stated that he had treated Broken Hill middlings. Broken Hill middlings had been largely produced in the past, and were still being produced, although to a much smaller extent; but except for some trial parcels which were from time to time sent over from Australia for experimental purposes, all the middlings (and tailings) were now re-treated at Broken Hill by concentration. He very much doubted whether the author ever got any Broken Hill middlings, the material probably being Broken Hill zinc concentrates; this matter was important, because the lower grade middlings required different treatment in smelting.

COMMUNICATIONS.

Mr. G. A. BOEDDICKER (Member of Council) wrote that he would take exception to a paragraph in that paper where the author said "the demand for zinc of very high standard of purity is somewhat limited." On the contrary, that demand was absolutely unlimited. There was not a user of spelter who would not prefer using absolutely pure spelter if the price were not prohibitive, and if, by general adoption of filters, the quality could be improved without increasing the cost by more than £1 or £2 per ton, there could be no reasonable doubt that all such pure zinc would be readily absorbed. Another statement of the author was to the effect that zinc fumes, which were always a cause of annoyance in the neighbourhood of zinc works, would be prevented. He (Mr. Boeddicker) thought the author should have added that that prevention would greatly tend to improve the health of the workmen employed at those works.

Mr. JOHN A. C. EDMISTON (Irvine) wrote regarding the difficulties which attended the use in practice of a fire-clay filter tube containing carbonaceous material, such as coke, as the filtering medium for purifying fume distilled from a zinc charge with any considerable percentage of lead.

These difficulties, incurring such grave disadvantages as to lead to the discarding of the process as originally patented, had seemingly been largely overcome in the modification described in this paper, but in what way or to what extent did not appear to him very clearly made out.

In the first place, if it was attempted to employ a very hard or dense material like anthracitic coke, so as to leave the medium occupying the interior filter tube throughout the distillation, then the zinc and lead were both absorbed.   In practice, that led to most serious trouble, as once the pores of the filter medium were clogged up the vapour could not freely pass round the swollen particles of coke, and very soon after distillation had commenced, the back pressure produced was so great as to cause excessive loss of zinc, either (*a*) as vapour through the pores· of hand-made retorts, or (*b*) through cracks caused by "butchering" of machine-made muffles.

On the other hand, by using a softer and more porous coke the pore-spaces of which were sufficient to allow a comparatively free passage for the mixed fume of zinc and lead, this had been found to further admit of the passage into the filter of unreduced particles of the charge. These oxides, together with small quantities of carbon dioxide formed in the earlier stages of the distillation, undoubtedly produced chemical reactions in the filter, the result of which was the oxidation of some of the carbon, sufficient in extent to partially consume the coke, cause both shrinkage and crumbling of the medium, and thereby afford a practically unobstructed passage for the unpurified fume direct to the condenser.

The corrugations suggested as serviceable in the filter tube seemed to him to present the same disadvantage, as the fume always took the path of least resistance, and passed along these channels unchecked and un-condensed, rather than traverse the packing, unless it was so very loosely filled as to be practically valueless.

Again, in place of the straight tube, it had been suggested to use a curved filter * in the form of a quadrant, which was quite impracticable, with even a small percentage of lead in the charge.

This, together with the ash in the oxidised coke, fell down into the centre of the receptacle which was at the lowest part of the circle, and completely shut up the passage from retort to condenser, until cleaned out by a pricker, which left the fume unchecked and unpurified as in the ordinary method of zinc smelting.

Mr. A. C. HOARE (Wednesbury) wrote that he had read Mr. Bannis-ter's paper with much interest, but it appeared to him there were several points which needed further explanation.

Considering that a charge was being worked under ordinary condi-tions, zinc vapour would be distilled over, and would pass into the receiver along with lead fume and carbon monoxide.   There the carbon monoxide would reduce the lead fume and deposit lead in the receiver along with the zinc, while excess carbon monoxide, together with uncon-densed zinc vapour, would burn at the mouth of the receiver, and the

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* *The Metal Industry*, December 1909, p. 203.

products of combustion pass up the flue. He had not yet seen a copy of Mr. Bannister's paper on "Cupellation Experiments—the Thermal Properties of Cupels," read before the Institution of Mining and Metallurgy, but he (Mr. Hoare) found in ordinary cupellation that the lead fume quickly passed out of the muffle if at a proper cupellation temperature ; therefore, he did not see why, under ordinary Belgian conditions, the lead fume could not be driven out without previous reduction in the receiver. Certainly it was true the zinc would follow the lead, because he saw the author pointed out that the zinc in the Hopkins process was much hotter than in the ordinary process, which went to show that the distillation was conducted at a much higher temperature (see later). He was not aware whether a pyrometer was used in the Hopkins process, because it appeared to him that the proper temperature for distillation and condensation of the zinc should be known ; then, if the maximum condensation temperature was employed, the lead fume might pass out of the receiver before reduction by the carbon monoxide. In a reducing atmosphere, as in a retort, one would think that lead would be formed, but he had not met with any records which went to show that lead was volatile, although he had proved, by quickly putting a cold porcelain crucible lid over a lead button undergoing cupellation, that lead oxide was volatile. (The object was to keep the lid cold and prevent any deposit becoming further oxidised.)

Referring to the Hopkins process, with which he understood Mr. Bannister had had considerable experience, it was stated that the lead was collected in the filter, together with zinc obtained from any, would be escaping zinc oxide, or zinc vapours. The author had pointed out that a greater yield was obtained, but he (Mr. Hoare) did not see how the zinc was returned from the pipe to the receiver—unless it ran back. It was certainly not back distilled, owing to the outward distillation pressure. It would be interesting to know the temperature of the incandescent filter. If zinc could be reduced from zinc fume in the carbonaceous filter, why should not lead be reduced also? He found from experiments, conducted in one of the Staffordshire County Metallurgical Laboratories, that it was much easier to reduce oxide of lead than oxide of zinc ; in fact, experiments went to show that zinc was only reduced at distillation temperature, and if that was so, then any zinc fume reduced in the pipe (if in the pipe long enough) would give zinc vapour, and this would be carried out of the pipe with the other escaping gases. That went to prove that the temperature of the filter must be about 950° C. Taking the melting-points of lead and zinc as 327° C. and 419° C. respectively, if lead was reduced in the pipe as well as zinc, why should not the lead run back into the receiver as well as zinc? The analysis of the coke after use as a filter would be very interesting, as this would show us the quantity of zinc and lead contained in the filter. The author had pointed out that no "skulling" took place in the ladles due to the metal being hotter. There appeared to be two reasons why the metal should be hotter :—

1. Protection of the receiver to some extent from external chilling effects by the hot carbonaceous filter. This would be brought about by

any circulating air being previously heated by the hot pipe. Internal chilling did not appear to be able to take place so long as distillation continued. It should also be borne in mind that the zinc would be at practically the same temperature (just a little hotter) as the receiver, therefore, if no " skulling " took place during pouring, due to the metal being hotter, more zinc fumes would be seen at the mouth of the receiver than in the ordinary Belgian process. He concluded from the above that if no "skulls" were obtained, there must be more zinc fume during tapping, or if there were no zinc fumes, then there was a likelihood of more "skulls" being produced.

2. Higher temperature of distillation. The zinc produced at a higher temperature might be due to a higher temperature of distillation, and that would account for the suggestion that the retorts were attacked by the charge, which would also be the case in ordinary Belgian practice. As the author pointed out that there was no great demand for pure zinc, there appeared no reason why the ordinary zinc smelter should not use "zinc ashes" if that source was cheaper.

Mr. Bannister had pointed out that little coke was consumed in the filter, from which it followed that little reduction took place, and less still if there was much carbon dioxide present to be converted into carbon monoxide. The analysis of the galvaniser's dross used, and the residue left in the retorts, would add to the interest of the paper.

Mr. J. S. G. PRIMROSE (Glasgow) wrote that undoubtedly fume filtration methods of zinc smelting and refining were bound to displace older methods of treating impure ores and products, and it seemed to him that it would be largely a question of comparative cost which would determine the one most universally adopted.

It was certainly the case that by placing an obstruction at the mouth of the retort there was a tendency to seriously impede the flow of vapours passing through to the condenser, but on account of its remaining unchanged throughout the day's working this was precisely where a refractory material as used in Brand's filter had a decided advantage over the carbonaceous packing, because if the latter were kept at a high temperature during the greater part of the day's run, then three defects were practically certain to occur. First, if the coke itself did not expand or cake, and seriously hinder the passage of the vapours, then as these continued depositing lead on the porous coke, the filter material would gradually become clogged, and only permit the gases and vapours to pass through the interspaces, exactly what took place when a packing of broken fire-brick was used; so that the two mediums simply acted in the capacity of refractory materials. Secondly, after a time, due to continued incandescence, shrinkage and crumbling of the coke takes place, thereby affording a free passage over the top of the filter medium, or along the corrugations of the filter tube, for the mixed vapours just at the time these were becoming more and more charged with lead. Finally, the whole filter may become choked with coke ash if excessive leakage were to take place or the carbon became completely oxidised.

On the other hand, if any attempt were made to save this combustion

of the carbonaceous filter, say by endeavouring to keep it "comparatively cool," then either zinc oxide films form into a sort of web over the mouth of the filter leading into the condenser, which, catching dust and carbon particles, would very soon choke the filter ; or in the attempt to prevent this choking, quite early in the distillation period it would be found necessary to work the furnace at a much higher temperature than otherwise would be needed, so that whilst a better yield might thus be attained, it could not be up to standard quality on account of the rapidity of the filtration, and the increased heat must certainly incur an increased destruction of the retorts.

It was stated on p. 216, that the "combined form of filter and stopper is used when the aim is to obtain a high quality zinc." Does this mean that the quality is improved at the expense of the yield, and that to obtain higher extraction the back filter must be dispensed with, and thus the quality suffers, so that the advantages (*a*) and (*c*) cannot be obtained together ?

With regard to the figures quoted on p. 218, as the result of refining galvaniser's dross, the complete significance of this can only be judged by knowing the lead and zinc content of the raw material, since "dross" is of very uncertain composition. Recent daily practice at Irvine with the Brand fire-brick filter was giving 99·9 per cent. spelter, and occasionally 99·92 per cent. of zinc in the first tapping with a smelting loss of no more than 7 units. This, however, was quite readily understood when it was stated that a higher grade of "dross" than usual was then available, as it contained less than 5 per cent. of lead and upwards of 85 per cent. of zinc.

On p. 218 it was claimed under advantage (*b*) that almost complete prevention of fume is effected by the use of the carbon packed "cork or nozzle," but absolutely the same result can be obtained from the Brand patent stopper, filled with any refractory material such as burnt fire-bricks broken to suitable size, or even the old retort tubes chipped down and the spinel portion rejected. These two latter materials may be reclaimed from the dump, and cost absolutely nil ; and it seemed rather useless to employ suitable hard coke costing probably 20s. per ton, simply to keep a larger blue flame than usual issuing from the nozzle, through which no air should be able to enter the condenser if the proper outflow of gas is maintained.

It was to be regretted that the tables on p. 221 gave no details of the amount of material used, its zinc and lead content, and the various smelting losses entailed. These must have fluctuated between very wide limits to give on the three consecutive days (October 11, 12, and 13, Table II.), first an increment of 17 per cent., and then a decrease of 22 per cent. on the "augmented" yield. The average "increase" for two successive weeks (November 23 and 30, Table I.) shows almost as badly by dropping from plus 13 per cent. to minus 6·3 per cent.

It was not a fair trial to compare tests run on one small portion of the furnace with the remainder of the retorts, or even to test material on one side of the furnace in contrast with the other side owing to unavoidable variations of the heating and temperature increment. It would be much

more conclusive to turn the whole furnace on to one and the same operation throughout.

Mr. C. O. Bannister wrote, in reply, that it was never intended, as assumed by Mr. Ridge, to put forward the Hopkins filters as a new zinc process, but rather as a modification of existing methods of smelting—in fact, it was claimed in the paper that no structural alterations of the furnaces were necessary, and that was considered a very great advantage. Judging by the amount of flame and fume depicted on the diagram shown by Mr. Ridge in illustration of Kleeman's patents, the efficiency was by no means great, nor was the arrangement convenient, and the whole thing was quite different to the Hopkins tube filters. With regard to the size of the condensers, Mr. Ridge very carefully pointed out all the advantages of large condensers, but said nothing of their disadvantages. Those were chiefly found in the difficulty of regulating the temperature of the liquid zinc, for if special precautions were not taken, chilling would take place, with its attendant troubles and losses. In order to overcome that difficulty it was usual to have an additional front to the furnace entailing considerable structural alterations, and even then the labour of cleaning out the retorts and recharging same was very much increased. He was pleased that Mr. Ridge recognised that, with the outer nozzle, a certain regulation of the temperature was obtained, and he would like to state that the regulation was quite noticeable even when the furnace was working too hot. With regard to the inner filter, all that was necessary at present was to state that it was placed in a suitable chamber fixed to the inner end of the condenser. With regard to the treatment of plumbiferous zinc, Mr. Ridge overlooked the fact that the method of settling he described required two operations—first, the casting into the large casting-ladle, and then recasting from the ladle, and in connection therewith some treatment of the lead separated must be necessary. The argument concerning the treatment of additional material by adding the residue from the filters was extremely feeble, when it was remembered that that would amount to only about 0·2 per cent., and the carbon thus added would take the place of carbon which would otherwise have to be added in the smelting mixture. The small amount of decrease in the capacity of the retorts, due to pushing the condenser farther in, was of no importance when the advantages of the process were taken into account, and provided the temperature was carefully regulated, no choking occurred in the filter.

In reply to Mr. Boeddicker, he quite agreed that the prevention of fume at the furnaces would tend to improve the health of the workmen, and would have considerable effect in lessening or stopping cases of lead poisoning among zinc smelters.

With regard to Mr. Edmiston's remarks concerning the nature of the carbon filters, the whole question was a matter of suitable coke at the correct temperature.

In reply to Mr. Hoare, he would point out that lead, though practically non-volatile *per se*, became volatilised to a considerable extent in the presence of certain metals, such as zinc. Lead oxide was, how-

ever, undoubtedly more volatile than metallic lead, and if Mr. Hoare caused lead oxide vapours from a muffle to pass through red-hot coke, he would find that they were reduced to the metallic state. The reason higher yields were obtained when the outer carbonaceous corks were employed was that oxidising conditions were prevented within the condenser, any air being sucked in due to the cooling of the furnace having to pass on its way through the hot coke, with the result that carbon monoxide was formed. No back distillation could take place, and any zinc dust and fine metal found in the corks was returned to a subsequent charge. The reason lead did not run back from the outer cork into the zinc was, that when reduced from lead fume by hot coke the lead assumed a very peculiar physical condition, the particles being coated with what appeared to be a very thin film of carbon, and in that state it was a most difficult matter to get the lead to run together in a liquid form, even at high temperatures.

In reply to Mr. Primrose, who advocated refractory material as a filtering medium, he would again point out that the reducing effect of the carbonaceous substance used in the Hopkins process had considerable advantages, and, when used, the choking of the inner filter would be much less than when other material was used. In the outside filter, refractory materials other than carbonaceous would be absolutely non-effective during the temporary periods of back pressure which occurred whenever the furnace was cooled. With proper conditions quality should not be obtained at the expense of quantity, and for high quality both filters should be used, whereas for quantity only the outer one was necessary. The reason for that should be obvious, for the packing of the inner filters necessitated a certain amount of additional labour. The causes of the fluctuations of yields throughout the furnace during the tests were mostly differences in ore mixtures, &c., over which there was no control, the object of the tests being to ascertain whether, by using the filters, better results could be obtained under ordinary conditions from any given charge ; and the tests had undoubtedly proved that better results could thus be obtained.

FIRST ANNUAL DINNER

The First Annual Dinner of the Institute was held at the Criterion Restaurant, Piccadilly, W., on Tuesday evening, January 18, 1910, Sir GERARD A. MUNTZ, Bart., President, occupying the chair.

There was an attendance of guests and members numbering about 175, amongst whom were :—

Vice-Chancellor HOPKINSON, K.C. (*The University of Manchester*).
The Right Hon. W. ELLISON-MACARTNEY (*Deputy Master of the Mint*).
Sir WALTER PRIDEAUX (*Clerk of the Goldsmiths' Company*).
Mr. H. F. DONALDSON, C.B. (*Chief Superintendent, Royal Ordnance Factory*).
Sir W. TILDEN, F.R.S.
Professor H. B. DIXON, F.R.S. (*President of the Chemical Society*).
Mr. J. A. F. ASPINALL (*President of the Institution of Mechanical Engineers*).
Mr. EDGAR TAYLOR (*President of the Institution of Mining and Metallurgy*).
Professor G. KAPP (*President of the Institution of Electrical Engineers*).
Dr. GLAZEBROOK, F.R.S. (*Director of the National Physical Laboratory*).
Engineer Vice-Admiral Sir JOHN DURSTON, K.C.B. (*late Engineer-in-Chief of the Royal Navy*).
Mr. A. MCARTHUR JOHNSTON (*President of the Chemical, Metallurgical, and Mining Society of South Africa*).
Sir W. H. WHITE, K.C.B., F.R.S. (*Past-President of the Institute of Metals*).
Professor GOWLAND, F.R.S. (*Vice-President*).
Professor A. K. HUNTINGTON, Assoc.R.S.M. (*Vice-President*).
Engineer Vice-Admiral H. J. ORAM, C.B. (*Vice-President*).
Sir HENRY A. WIGGIN, Bart. (*Vice-President*).
Mr. T. A. BAYLISS (*Member of Council*).
Mr. G. A. BOEDDICKER (*Member of Council*).
Mr. R. KAYE GRAY (*Member of Council*).
Mr. J. T. MILTON (*Member of Council*).
Mr. A. E. SEATON (*Member of Council*).
Mr. W. H. JOHNSON, B.Sc. (*Honorary Secretary*).
Professor T. TURNER, M.Sc. (*Honorary Treasurer*).

The PRESIDENT gave the toast of "His Majesty the King," which was drunk with musical honours.

"THE INSTITUTE OF METALS"

Vice-Chancellor HOPKINSON, K.C. (The University of Manchester), in proposing the toast of the Institute of Metals, said : Mr. President and Gentlemen,—I could not at first understand why I of all people should have been selected to propose this most important toast. The question is like one of those that arises in connection with the British Constitution, being sometimes difficult to answer, but I have no doubt there is a very good answer indeed to it. I do deem it an honour to have had this toast given to me to propose, but at the same time it seems rather

amusing as well as a high compliment, and I do deem it also a thing
that can be justified on the soundest scientific principles, certainly on
the soundest principles and precedents of English public action.   It is
a very good thing to trust an important duty of this kind to the one
of all others here present who probably knows least about the subject
in hand, and if he can make a good case of it, how very good indeed
the case of the toast must be.   Q.E.D. as used to be said in Euclid.
I have also the pleasure to couple with this toast the name of your
new President recently elected.   I have had the honour for some
time of the acquaintance of your late President, under whose auspices
the work of this Institute was started, and I have had the honour
of knowing one or two other members in my own town who have
taken an active part in it, especially my friends Mr. Johnson and
Professor Carpenter, who I am sorry to say is prevented by illness from
being with us to-day.   I am glad to know that the work that is being
carried on under the direction of your new President, whose family
have been for three generations at least associated specially with depart-
ments of metallurgical work, and whose name is familiar even to us
outsiders in connection with the name of a most useful metal, is making
excellent progress.   If there are some of us who do not agree with some
of the things that are being said now in the strife of parties, we are all of
us patriots enough to acknowledge the debt we owe to those who made
our wooden walls secure in past times by the coating which they re-
ceived from that valuable metal.   I hope I shall not be accused of
trespassing on any party political matter, or of becoming too violent an
advocate of the heredity principle, if I say that the honour and the
advantage which we derive from the association of the President with
this Institution is enhanced by the fact that it is not only our present
President, but also his father and grandfather, to whom we look as men
who have done great things for the country in connection with metals.
Then I am glad to be here—you will not believe that anybody can
say honestly that they are glad to be making an after-dinner speech
—but I am glad to be here for this reason, that I know you have
asked me to come and speak, not because I know anything specially
of the subject, but merely as the representative of one—and I think
for present purposes I may claim to say all—of those Universities which
are trying to the best of their ability to do something to advance
science, and also to make that science practically useful by working in
association with those who know what the practical problems of life
are.   It is a recognition of a great modern movement from which
we hope to achieve great results—I mean the association of the men
of science with the men of practice.   I do not think we can draw
any hard and fast line between the two, and I am certain of this,
that the two can aid each other enormously.   It is of vital import-
ance—I know, not so much from my own knowledge, as from dis-
cussing the matter with my colleagues—for the men of science to
know when there are certain practical problems which need solution,
and that he should be asked to face those practical problems with all
the theoretical knowledge at his disposal, and by means of quiet work

in his laboratories, and above all, that in carrying out investigation he should have the advantage of the association of senior students and of assistants who can help him in that work and bring youthful enthusiasm to bear upon it. On the other hand, I may just quote an example of one large manufacturer in the district with which I am specially associated, who said that he had a problem to solve, and that he worked hard at it, and spent considerable sums of money on it. After carrying on his research for a couple of years or so he ascertained from some scientific paper, which he might have discovered before by inquiring from scientific men associated with the work of scientific societies, that the problem had already been solved, and that he could have used the material which would have been ready to his hands had he known where to look for it. Then I should like to allude to one other side of the work of this Institute, which has succeeded so rapidly since it was started one and a half years ago. It is a thing that seems a little strange perhaps to an outsider, but it is one of the marks of what is best in English life, whether business life or professional life—I mean the fact that you are ready at your meetings, by means of papers and my means of correspondence, to place at the disposal of other members who are engaged in the same industry, and who may be your competitors, a great deal of the knowledge which you yourselves have. Of course there are limits to that, but it is a remarkable thing in every phase of English life, that those who are engaged in the same profession or the same industry are so constantly ready to aid each other with information from the materials they have at hand, and by the advantageous action which they can take together with mutual goodwill. Speaking of one's own profession, I always thought it was rather a strange thing that where men are such keen rivals in the world, and where so much depends upon their effort and success in competition, that we are such good friends personally, and so ready to help each other with advice. I am speaking of my own old profession of the Bar, and I believe the same thing exists amongst those who are engaged in many other pursuits. Competition, and hard competition, must and will exist, but it exists alongside with mutual goodwill, with mutual respect, and readiness to give help to one another and to advance the industry as a whole. Now I shall be led very soon beyond my depth if I venture to say very much more with regard to the scope of the work of the Institute, but I am inclined to look back historically, and say that if there is one thing that really is the "differentia" between man and the lower animals, it is that man is a worker in metals and the lower animals are not. I believe the highest scientific authorities say in these days that Adam and Eve were not exactly human beings, but might rather be called anthropoid, and that the person who was the real founder of the human race of men and women as civilised beings was not Adam, still less the original Cain or the unfortunate Abel, but that Tubal Cain was the real man—he was our great progenitor, and the first of the real self-respecting human beings capable of progress. I am quite sure that from the practical side your Institute has an immense amount of work to do. Looking back again historically for a moment

—I am going now from the scriptural to the archæological account, for in our universities we take all these subjects in at once, and one is bound to express interest in them all, however imperfectly— but if we look back to the archæological or mythical accounts, there there is an ancient theory that there was a Golden Age, and perhaps we are coming again to that some time, no doubt, ultimately by the work of this Institute. But even if sceptics put aside this as a dream of the poets, it is sober fact that the great age, the best age of all, was not the Stone Age certainly—that was barbarous ; it was not the Iron Age or the Steel Age, which we are in now ; it was the Bronze Age. That was the age for Art; that was the age when the finest beginnings of early literature and early art were developed, and it is partly because you are bringing back again the Bronze Age that we who look at things from a historical point of view are amongst those who humbly, to the best of our ability, desire to see the work of this Institute advanced. In conclusion, I may sum up by saying that I do think it is a very important thing that, by the association of men of science and men engaged in actual practice, we see able minds directed to those infinitely various problems that arise as to the uses, the production, and the combination of the different metals. How far that knowledge may advance, what its results ultimately may be, nobody can tell, but you can say this certainly, they will be far reaching and valuable. What chance would there have been for introducing the enormous power of electricity unless it had been understood what the properties of the metals were that are used in the production and in the distribution of electrical force? And so with all manner of industries. No advance I believe is possible from the practical point of view unless people thoroughly understand what are the enormous capacities wrapt up in metals of various kinds, and the infinite combinations of which they are capable. It gives me the heartiest satisfaction to propose your continued success, continued progress in the same rapid way that the Institute has already progressed. I do so for these three reasons, that, first, you are promoting the advance of knowledge—and it is always something for a human being to extend the range of his knowledge even for its own sake ; secondly, you are enabling the conditions of life to be made brighter and pleasanter as every advance in practical science may make them if rightly used ; and, thirdly, you are doing what no contentions as to tariff or anti-tariff can do, you are making it possible for Britain to maintain its position in the world, making it possible for its people to be fed by their own ordered and enlightened exertions. That can only be done by those who see that every opportunity is used for making the knowledge that comes from scientific study available in practical life, and so promoting the industries of the country which we love so well.

The PRESIDENT, in responding said : Vice-Chancellor Hopkinson and Gentlemen,—I thank you, sir, for the very kind and eloquent way in which you have proposed this toast of the Institute, and you, gentlemen, for the way in which you have received it. I think the Vice-Chancellor

has placed the duties of the Institute before us in a light which may not have occurred to many of us before. He had made us almost a charitable institution. I had not realised previously what our work was. I thought it was more or less of a selfish nature, but from what the Vice-Chancellor has said, it appears to me that we have to be somewhat of public benefactors, and that the knowledge which we are acquiring, or are going to acquire, will be of even larger service than had occurred to most of us previously. I am afraid that, judged up to the present, we are not quite as virtuous as the Vice-Chancellor would make us out, that is to say, with regard to the interchange of knowledge between members. I complained this morning in my Presidential Address—and I still have cause to complain—that we are not yet sufficiently communicative one to another. I trust that in view of what we have heard this evening many of us may be, if I may say it without being rude, shamed into greater generosity in that respect. If we are to be of such service to humanity as the Vice-Chancellor has sketched out—and I trust we are all desirous of filling the post of philanthropists—it is quite evident that we must as far as possible, without going beyond reasonable limits, give as much knowledge as we may possess to our fellow-members in order that the science of non-ferrous metallurgy may have an even better chance of being exploited. The Vice-Chancellor has taken us back to the great age, the Bronze Age, the age of Homer and the Greek heroes. I do not know if you feel like the Greek heroes to-night, or feel inclined to quote Homer. I used to know something of Homer years ago, but I am afraid it has gone away from me now, but I have always admired the Greek heroes. They wore bronze armour and carried bronze instruments which would puzzle most copper-makers to produce to-day, if the accounts that have passed down to us by tradition, and not so much by writing, are true. I do not think there was any specification for the making of Achilles' sword. I do not think tensile strength was mentioned in connection with it; but there is no doubt there was a considerable amount of tensile strength and elongation in the Greek spear to enable it to do what it did do, otherwise the composition of the bronze armour which was worn by the Greek warriors, and which I believe the spears occasionally penetrated, was not up to the specification. In drinking the toast of the Institute of Metals many of us have, to a certain extent, been drinking our own healths. We are all members of this Institute, and success to the Institute means success to the members here. But I think to-night we are somewhat justified in self-congratulation. It has been said in the past—I do not know who said it, but it is a well-known saying—that an Englishman never considers he has done anything worth calling anything unless he has had a dinner attached to it. We are met here to-night on the first occasion to dine together, to celebrate what we may call our incorporation—nothing injurious intended—and therefore I think we are entitled to consider that we have anyhow done something, even if what we had previously done during the day was not of much account, although personally I am bound to confess that even before the dinner stage was arrived at

I felt we had accomplished considerable things to-day. Those of us who were at the morning session must have felt that, even if nothing else had occurred than the opportunity of listening to such papers as we had placed before us this morning and the discussions which ensued upon them, it was well worth the meetings being held. At the same time there is an old saying that "All work and no play makes Jack a dull boy," and I am sure it is good for us, and good for all men, to meet together occasionally in assemblies of this nature, to set aside for the time being the more serious matters of life, to meet round the table, and to get to know each other better—to become more intimate with our fellow-men, to found new friendships and see each other on a new basis. The brain after a certain amount of hard work gets jaded, and the brain as well as the body requires a rest. Occasionally we like a change from such things as well. The ex-President mentioned the word "eutectics" and such things, but we like to change to lighter lines when we get round the dinner table. The brain gets weary of everything, even of politics. I am glad to-night that I am not called upon to speak upon politics ; we are debarred from that on this occasion, therefore I need not refer to the subject. The Vice-Chancellor has gracefully gone as near to politics as possible without speaking of them, but that is a science of which every one is not capable. I feel that I ought to a large extent, in fact altogether, limit any reference to metallurgical subjects or the science of metallurgy at this dinner to the merest outline. At the same time I feel I must make an exception in referring to the visit to His Majesty's Mint which many of us have been privileged to make to-day, thanks to the kindness of the authorities. We have had a most interesting tour, and were able to witness the process of making money, a process with regard to which most of us are only too pleased to take any hint. It is very gratifying to me to-night as your President to see such a very goodly gathering of our members here. It shows a spirit of interest in the Institute, and a feeling of *esprit de corps* such as is absolutely essential for the success of an institute such as ours. I do not wish to trespass upon the ground which is reserved to a fellow-member a little later on, but I should not like to sit down without making some comment on what I am sure we must all feel—the great gratification at seeing so many distinguished gentlemen amongst us as guests to-night—members of kindred institutions and other great societies. It shows a spirit of kindly consideration and interest in this Institute which I am sure must be most encouraging to all of us. It will encourage us to greater efforts in the future to live up to those very flattering suggestions the Vice-Chancellor has made on our behalf. In such company as I have around me I feel rather like the proverbial minnow amongst the whales, and I rather wonder how I come to be occupying the position I do of presiding over the meeting. It makes me more than ever realise the honour you have done me in electing me to be your President. You have set me a difficult task, and you have yourselves undertaken a very great work in the establishment of this Institute ; but I feel sure that you have undertaken it in the right spirit to ensure success, that you will go forward to success, and that the

Institute will flourish.   As years pass, one following the other, I hope when the annual meetings and these annual dinners take place that those of us who are here to-night and who may be here then will be able to look back, perhaps with surprise and wonder, that small beginnings have grown into such big endings.   For my own part I shall always look back with pride and pleasure to having had the honour of being your President at the first annual banquet of this Institute.   I assure you that anything I can do to live up to the ideals which the Vice-Chancellor has placed before us, and anything I can do to aid the Institute and assist in its advancement, will always be done by me with my whole heart.

"Kindred Societies."

Mr. A. E. Seaton, Member of Council, in proposing the toast, said: Mr. President and Gentlemen,—Some year or two ago I had the privilege of dining with a society known as "The Odd Volumes," and I discovered that, by Rule 15, if a member spoke on anything he understood he was immediately fined.   Having this in view, I suppose I have been chosen to-night to propose this toast.   I do not happen even to be a metallurgist; I am simply an engineer.   But it gives me very great pleasure, nevertheless, to have an opportunity of testifying to the very great kindness we have received from what are called on the toast list "Kindred Societies."   When a man begins to talk about his kindred he has to deal with the question of genealogy. Our genealogy has to be looked into.   Whose child are we?   Who are our parents?   Where do we come from?   Well, we are directly descended from that venerable Society which was founded and so distinguished itself in the time of Charles II.—the Royal Society.   It made early attempts to carry out the functions of an Institute of Metals; and it is very interesting, if not instructive, to read the papers and the debates of that venerable Society.   I often wonder whether our great-grandchildren, when they come to read the debates of the various societies to which I belong, will obtain the same enjoyment as I very frequently get from reading the transactions of ancient institutions.   I suppose there is no question that, whoever's child we are, we are the foster-child of the Institution of Mechanical Engineers. It is, therefore, very appropriate that the first name I have to associate with the toast I am now about to propose is that of my good friend Mr. Aspinall, a gentleman well known, not only to you here, but throughout the length and breadth of the land, as an illustration of what is a fact well known to many of you, that a well-trained engineer can turn his hand to anything, even to the management of a big railway.   The only thing, I understand, an engineer cannot undertake is the management of a big hotel, but I am not quite sure that this can be said of Mr. Aspinall.   But, seriously, we owe very much to the Institution over which Mr. Aspinall presides.   Literally they have been to us a foster-mother; and from that Institution we have recruited very largely our members, who now

number something over five hundred. So that I suppose we have some little right to consider ourselves kindred with them. So likewise with the other institutions. Our first President was Sir William White. There may be one institution that Sir William White is not a member of, but can anybody say that Sir William White has not been President of every institution to which he belongs? Therefore through Sir William White I may say we are kindred with the whole of those societies, for, as our first father, we claim kinship with those to whom he is related. The Vice-Chancellor to-night, in his very admirable and eloquent speech, introduced something that has given me a bit of a text on which I can say something; but do not suppose it is something I know anything about, or you might fine me. It is, nevertheless, a somewhat singular fact. You have heard of the Stone Age, the Bronze Age, and the Iron Age; but the strangest thing is that in the vision of the prophet Daniel the age succeeding that of iron is to be one of "clay"—the Bible translation of the word is "clay." But I believe "clay" means really aluminium, and if that be so, what is the future of this Institution? because it will be our function to deal with aluminium and all that belongs to it, being a non-ferrous metal—at least generally it is a non-ferrous metal. Allusion was also made to the wonderful cutting-tools produced in the past, not only by the Egyptians and the Asiatic nations, but also by those nations that inhabited Central and South America at a period when there was a civilisation there almost equal to that of Babylon and Egypt. They must have had cutting-tools of bronze, because we have, I think, pretty good evidence that it was the metal they used, and we know that copper is to-day largely imported from Chili and the western coast of America. But what has not been discovered, and what remains to this Institute to discover, is a bronze that, while being tough, is at the same time in parts hard, the hardness, moreover, being consistent with cutting without breaking up. All the attempts with which I am acquainted to make a cutting-tool out of bronze have ended generally in producing an alloy very hard, but which usually breaks under shock, and therefore could not be used with a hammer. There is no question that whatever the metal was the ancient Egyptians used, it must have been one of exceedingly fine grain to have permitted of those very hard syenite rocks being hewn and cut into delicate shapes and incised, as you may see them to-day in almost any museum. I still think, however, that steel must have played a part in that work; but of course I have no proof of it. I feel, therefore, that this Institution has a very great future before it as the handmaiden of the other institutions. Much that we do—in fact, all that we shall do—will probably not be so much of advantage to ourselves as to those engineers, electricians, and others who will continue to turn to a practical use the discoveries that this Institution will probably evolve. But whether that be so, or whether it runs on its own lines independently of others, it will always, I know, have a very kindly feeling for kindred institutions, just as in this country it prevails, and always has prevailed, amongst scientific institutions, even between the oldest and the youngest.

I therefore ask you to drink the health of our "Kindred Societies," and to associate with the toast the name of Mr. J. A. F. Aspinall, President of the Institution of Mechanical Engineers; Professor H. B. Dixon, President of the Chemical Society; and Mr. Edgar Taylor, President of the Institution of Mining and Metallurgy.

Mr. J. A. F. ASPINALL (President of the Institution of Mechanical Engineers), in responding, said : Mr. President and Gentlemen,—I have to thank Mr. Seaton for the very kind way in which he has proposed the toast of the Institution of Mechanical Engineers. That Institution has always been only too glad, through its Council, aided and abetted by its Past-President, Sir William White, to extend to you the hospitality of its rooms, and it hopes that you will continue to use them as much as ever you can for the benefit of engineering work. When I was coming along here this evening, and I saw the anxiety which is displayed in the numbers which are put up on certain placards, I could not help thinking that it was a very much prouder thing to be a member of the Institute of Metals than it was to be a member of Parliament. At that factory down at Westminster they are ever sitting early and late manufacturing something, which they do very badly. There is nothing they produce that is not full of blow-holes and flaws ; and you can quite understand that, now Parliament has got within its walls so many lawyers, it is to their interest that the laws should be turned out in an imperfect state in order that their real value may be tested when they get down to the Law Courts. I believe that in China it is the rule that if you have a family doctor you pay him so long as everybody at home is well, but the moment anybody becomes ill you cease to pay your doctor. Now I feel that if I were a politician, which I am not, I should be entirely in favour of the payment of members—so long as they stayed away from the House. You know that, as manufacturers and as engineers, we have been suffering from a long period of depression. Now if the members of the House of Commons would only stay away for three or four years, really we might be able to get on with our business and try and make a little money. However, I suppose that is not to be. I rejoice at seeing so many of you gentlemen who are connected with our own Institution of Mechanical Engineers joining the Institute of Metals. I am interested to learn from Mr. Seaton that you have already got five hundred members, which is practically 10 per cent. of the number of members of the Institution of Mechanical Engineers. I hope that your Institution will grow and prosper. It is your interest to produce non-ferrous metal, but really true metal, and in that way you are going to do better than that other factory to which I have referred. Surely it is your intention at some time to give to the mechanical engineer those things which he wants. You intend to give us something—whether it be aluminium or not referred to by Mr. Seaton I do not know—but something which is extremely light but yet intensely strong. If it be some other form of non-ferrous metal, if it be very malleable but yet extremely durable, you are going to help the engineer, the shipbuilder,

and everybody who is interested in the production of any kind of mechanical article. I assume, from the presence of the Deputy-Master of the Mint here this evening, that you will not despise dabbling in the question of gold. The alchemists of old thought that they could turn their metals into gold. You, on the other hand, I trust, are going to produce metals of such a character that it will turn large quantities of gold into your own pockets, and give to the engineers of the future something which will be useful, so that you may say that you have done well for posterity, and that you have handed down to the future that which is going to be of use for all time.

Professor H. B. Dixon (President of the Chemical Society), who also responded, said: Mr. President and Gentlemen,—It is a high honour and also a very great pleasure to me, as President of the Chemical Society, to respond to this toast, and to welcome, on behalf of the parent Society, the successful *début* of its youngest daughter, the Institute of Metals. I hope no one will think—not even the youngest metallurgist present—that I am offensively patronising in speaking of parent and daughter. I well remember the rebuke once administered by an undergraduate to a tutor at Oxford who reproved him for his overweening ways, and ended a little lecture to him by saying "I believe, Mr. So-and-so, you are the most conceited man in this college", and the undergraduate replied 'Well, sir, *for an undergraduate* perhaps I am.' I in no way wish to suggest that chemistry is on a different plane from metallurgy. But I think that metallurgy rightly starts from chemistry. I have taken an active part in my own University in founding a Chair of Metallurgy; and I rejoice that several of the men we have trained in chemistry are now metallurgists, and good metallurgists, I believe, because they were good chemists first. I do not think that the founders of this Institute in any way wish to dissociate themselves from chemistry. I rather think that any dissociation they contemplate is the special spinning up of a study which, starting from the basis of chemistry, comes back to it, as all proper dissociations do, by a reversible process, and illuminates and enriches that which it started from. I believe the researches of this Institute may throw as much light on chemistry in the future as we know historically that metallurgy did at the dawn of our science. Indeed, I think I could maintain the thesis that chemistry had its very origin in work done on metalliferous ores, if I had not been warned that I must not use any name beginning or ending with "ferrous." You, I am told, must not have any ferrous or ferric iron in the fire, but you may have practically all the other metals. As a disciple of Mendeleef, I think you have the best of it according to the doctrine of Periodicity. You have to deal with all the real working metallic elements, with their regular gradation of properties culminating in the seventh series, and then beginning again with a new octave. The iron and steel people have to be content with a small group of metals in a mere transitional series, many of whose members have no chemistry at all. The whole periodic table is yours! The table where

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you have so kindly entertained us to-night, is the first of your series. I hope that series will be a long and brilliant one, and when your octave recurs I trust and believe you, like your metals, will be found with a higher number, a greater activity, and a still stronger influence. I beg to thank you.

Mr. EDGAR TAYLOR (President of the Institution of Mining and Metallurgy), who also responded, said : Mr. President, Mr. Seaton, and Gentlemen,—It remains for me, as the President of the Institution of Mining and Metallurgy, to extend to the members of this Institute of Metals an expression of gratification, and indeed of delight, that you have come to London to establish your Institution.   Our scientific interests and scientific aspirations are undoubtedly very closely allied. I may be allowed to say, I think, that the aspirations of the Institution which I represent here to-night are those rather of the producers, while yours are those rather of the finishers.   Our ambitions have been great, and we have succeeded in a great measure.   Our Institution now has a very large membership, and we think we have been very successful. I cannot do better than wish to you, as an Institution, a similar success. It is a great pleasure to me personally to be present to-night, because I have all my life been associated not only with mining, but with the metallurgy of all kinds of metals—the metallurgy only in the more amateur sense, because my business, of course, is that of mining, and the metallurgical part of our business as miners is looked after by the trained metallurgist before it comes to the hands of you gentlemen of the Institute of Metals.   There is nothing which our two Institutions cannot most properly reciprocate.   I believe our two Institutions should, and will, work with the most gratifying unanimity on all subjects, and I am sure I am expressing the views not only of the Council of the Institution which I now represent, but of its members also in making that statement.   Gentlemen, I thank you extremely for having invited me to your first repast, and I thank you also for having proposed this toast, coupled with the name of the Institution which I represent.

"THE GUESTS."

Professor T. TURNER, M.Sc. (Hon. Treasurer), in proposing the toast, said : Mr. President and Gentlemen,—It falls to my lot to propose a toast which I am quite sure you will all drink right heartily, namely, the toast of the guests who are with us this evening.   You are aware that we invite guests on an occasion such as this for two reasons.   In the first place, we wish to honour men whose position and whose work we respect and admire ; and, in the second place, we wish to honour ourselves by having at our table men who are thus eminent, and who can sympathise with our aims and our ambitions.   The President has already told us that we have here—and we are very glad to recognise them —a considerable number of distinguished men, who are, as we have heard, largely associated with kindred societies.   We should at any other time of the year have had other distinguished guests who we are

sorry not to have with us to-night. We should have had, for example, representatives of leading members of both political parties. I understand that those gentlemen are at present otherwise engaged, and that some of them are disengaged. But though we have not the opportunity of welcoming those gentlemen, we have many guests here, some of whom have spoken to us already, and others whom we hope to hear shortly. I have been asked to couple with this toast three names, and I am sure when you hear those names you will feel that every one of them is deserving of our respect and our thanks for their presence here to-night. In the first place, we have with us the Right Hon. William Ellison-Macartney, the Deputy-Master of the Mint, who, having already served his country in connection with its naval defence, is now taking charge of that part of metallurgy which converts metal in that form in which most of us are more particularly interested. We are very much indebted to him and to all the officials of the Mint for the very excellent facilities which were afforded us of seeing the various stages of the production of finished coinage from the raw metal. In reference to the two other guests who are on the toast-list to-night, I am glad to recognise in them fellow-members of my own University. I believe it is generally recognised that the citizens of Birmingham are a very united people. We have taken for our motto the words of a little maid who came from North Wales—a country from which a very celebrated politician of the present day hails—and that motto, which, you remember, came up every time the maiden was questioned, was, "We are seven." Now this united character, which I believe is typical of the Birmingham people, extends also into our University life. It is quite true that we have differences of opinion on matters of politics, that we have differences of opinion on matters of religion, and on other serious and important subjects, but through it all we have ever, during the ten years of our existence as members of the University, worked together with the very best possible spirit. Looking back through all the meetings I have attended, I can say I do not remember one unkind word that has ever been spoken by one member of the University to another. I have therefore very much pleasure in coupling with this toast the name of my friend and colleague, Professor Kapp. Professor Kapp appears before us to-night in a double capacity, first as President of one of the largest—I am not quite sure if it is not the largest—of the scientific societies, although it is one of the youngest, namely, the Institution of Electrical Engineers. In that capacity he has earned the respect and, I believe I may say almost more than that, the affection of his colleagues throughout not only this country, but on the Continent and every other part of the world. I believe I am revealing no secret when I say that Professor Kapp is a most genial and good-tempered man. In proof of this I say that I have travelled with him, I have lived with him, and have even slept with him, but have never quarrelled with him. There is one other guest that we shall be delighted to honour to-night—Sir William Tilden—who took such an active part about the year 1892 in Birmingham in the early discussions which led to the formation of what we are proud to think is the first of those institutions

which we now call the New Universities. Having made his name
originally at Clifton, and spent something like a dozen years in Birming-
ham ; being for another twelve years or so Professor at the Royal College
of Science, and being responsible for the design and equipment of those
magnificent laboratories which are now installed at South Kensington ;
having been President of the Chemical Society, President of the Society
of Chemical Industry, of the Institute of Chemistry, and I am not quite
sure how many other societies, he has occupied an eminent position
which has quite recently been recognised by the conferment of a knight-
hood upon him by His Majesty, and of an honorary degree by the
University of Birmingham. I am not quite sure which is the greater
honour of the two. I would like to say one concluding word, although
it is a personal one, and that is, that it was my privilege during a period
of something like ten years to have Dr. Tilden as my chief. During
those years, which were some of the happiest of the whole of my life, I
was able to do the best of my work. It was my most prolific time, in
connection, at all events, with publications ; and it is not too much
to say that when I look upon Dr. Tilden, I have towards him feelings
both of affection and respect. I have, therefore, gentlemen, to give you
the toast of "Our Guests," coupled with the names of the Right Hon.
William Ellison-Macartney, Professor Kapp, and Sir William Tilden.

The Right Hon. WILLIAM ELLISON-MACARTNEY (Deputy-Master of
the Mint) in responding, said : Mr. President, Professor Turner, and
Gentlemen,—As my native modesty is as unlimited as the celebrated
cruse of oil which in ancient days belonged to a certain widow, I should
almost feel inclined to blush at finding my name associated with this
toast, if I did not recollect that the person who ought to blush for my
situation on this occasion is Sir William White. I would call upon him
to blush if I were not aware that, having filled the office of President in
almost every modern scientific and technical society that exists in the
United Kingdom, he has naturally lost all power of expressing that
humane and natural emotion. I am associated with what are generally
called—not very scientifically—the precious metals. My knowledge
of them—my scientific knowledge of them—I possess in the most con-
venient form—by deputy. But I have observed during my six years
of office at the Mint that these precious metals in the course of their
transformation into the current coin of the realm, by what appears to
me a very simple process of manufacture, exhibit the most extra-
ordinary humours. So eccentric are they at times that I am almost
ready to compare them with the freaks of the suffragettes. I feel
sure that if Hamlet had in the course of his lifetime occupied the
office which I now officially fill, he would have varied one of his most
celebrated sayings and said, " Frailty, thy name is metal." Gentlemen,
I have been warned by one of your most distinguished members that on
no account should I attempt to say anything about the real objects of
your pursuit, and therefore under those circumstances I happily recollect
that a man once said—I will not say whether he was a wise man or a
fool—that a Scotchman thought before he spoke, that an Englishman

thought while he spoke, and that an Irishman spoke first and thought afterwards. Now, I am confident that if ever I am to take advantage of my native privileges, this is the time to put off till to-morrow morning, or even till to-morrow afternoon, or perhaps till the end of the General Election, any reflections I may have to make upon what I say now. I feel that it is a great privilege to me to be able to respond for the Vice-Chancellor and myself, more particularly because it is a comfort to find that there is a Vice-Chancellor almost as ignorant as I am myself of the objects which collect you all together. But, gentlemen, I assure you I sincerely appreciate the honour you have done me to-night in my official position in inviting me to your dinner, and I deeply regret that a peremptory summons away on business prevented me being present in person to welcome your President and the members of the Institute who visited the Royal Mint this afternoon. And now I think I have fulfilled my duty to-night—the duty cast upon me of responding for those visitors who are in a state of dire ignorance. I leave it to my successors, if they are able, to reply for those who pretend to have some knowledge on matters in which your Institute is most interested.

Professor G. KAPP, M.Sc. (President of the Institution of Electrical Engineers), who also responded, said : Mr. President, Professor Turner, and Gentlemen,—I take it as a great privilege that you allow me to respond to the toast which you have drunk, the toast of your guests, in such a cordial and enthusiastic manner. Professor Dixon has told us that your Institute is a daughter of chemical science, in fact he said she was still an infant. I can corroborate that statement, because I see her taking her first bottle to-night. She is a vigorous infant, who we hope will grow and prosper. Besides giving us this substantial and most enjoyable dinner, I feel that we are indebted to your Institute, or at least to the individual members of your Institute, for giving us the material that we can work upon. Professor Turner was good enough to mention that I came here in a dual capacity, first as a mere guest, and secondly as a representative of that branch of engineering which perhaps more than any other is dependent upon the work of metallurgists. If one considers how important it is to have pure copper for electrical engineering purposes, one can appreciate the value of the work which you are doing. You are laying one part of the foundation for us to build upon ; the other part, namely iron, you do not touch, but it is remarkable that, thanks to the research work of the metallurgist, a substitute for iron has been discovered. There is an alloy which, although containing no iron whatever, has the magnetic qualities of iron. The components taken by themselves are non-magnetic, yet in some mysterious way the combination is magnetic. Hitherto nobody has found out why this is so, and we electricians look to you to tell us why it is that copper and other non-magnetic metals fused together shall produce something which can be magnetised. Electrical engineers require copper, and the purer they get it the better. It is due to your work that we can get copper which has more than 100 per cent. conductivity. That sounds

ridiculous, and naturally you laugh, but the standard of copper was set at a time when the work of the metallurgist was not so advanced as it is now. Those men who produced copper in the days when Matheson set his standard did not produce pure copper, though they thought it was pure, and Matheson, thinking it had the best conductivity which copper could have, called it 100 per cent.; but nowadays you are giving us copper of 101 per cent. and even 102 per cent. conductivity. I hope you will improve it further, and go on and give us infinite conductivity, and then we should be able to make machines which waste no power. Gentlemen, I thank you on behalf of the guests and myself for the cordial manner in which you have drunk this toast, and for the entertainment you have given us to-night.

Sir WILLIAM A. TILDEN, who also responded, said: Mr. President, Professor Turner, and Gentlemen,—I always think there are several advantages in being called upon to speak last on an occasion like this; in the first place, because one is in a position to claim that if one had only had an opportunity earlier in the evening one might have said things quite as interesting and quite as brilliant as those which have been uttered by the previous speakers; secondly, because at this stage of the proceedings one is always called upon to be extremely brief. In view of the requirements of this position naturally I have been able to enjoy my dinner in a manner which I imagine it has not been enjoyed possibly by those speakers who preceded me, and who had speeches on their minds. I shall, therefore, with your permission limit myself to expressing to my old friend Professor Turner my most cordial thanks for the kindly way in which he has referred to me, and to trust, as I have not the slightest doubt will be the case, that our friendship will extend to the end of my life. I should like also to express to you, gentlemen, and the members generally, my most heartfelt wishes for the prosperity of the new institution. I feel confident that it has before it a great career of usefulness and importance. In conclusion, all I can say is that I thank you very heartily for giving me an opportunity of meeting so many old friends to-night who are interested in the establishment of the Institute of Metals.

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

CONTENTS.

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ORES AND MINERALS.

CONTENTS.

I.—OCCURRENCE.

Copper.—C. F. Tolman * examines the economic importance of copper, and considers the extent and probable life of the world's supplies of copper minerals. He shows the important *rôle* which low-grade ores will play in the future history of copper, and directs particular attention to that type of deposit most recently developed in the United States, the chalcocite disseminations in schist, the engineering and economic aspects of which he discusses at length.

Cupriferous Calcite.—A red variety of calcite occurring at Capo Calamita, Elba, has been found by F. Millosevich † to contain 2·02 per cent. of cobalt carbonate.

Mineral Resources of the Philippines.—M. Wooley ‡ in an article on the natural resources of the Philippine Islands gives some account of the mineral deposits. He states that the extent of the mineral wealth of the Philippines is comparatively unknown, the varieties of ores are extensive, and the veins and ore deposits abundant. The minerals mentioned as occurring include coal, gold, silver, platinum, mercury, lead, copper, iron, sulphur, marble, kaolin, and asbestos.

Lead and Zinc Ores in Virginia.—M. M. Caldwell § gives an account of the lead and zinc ores of Virginia. In Rye Valley, Smyth County, there appears to be a true fissure vein of beautiful galena, extremely pure. On a property near Cripple Creek Station, during developments for iron ore, the shaft penetrated from 1 to 3 feet of

* *Engineering Magazine*, March 1910, vol. xxxviii., No. 6, pp. 893-904.
† *Atti della Reale Accademia dei Lincei*, 1910, vol. xix., No. 2, pp. 91-92.
‡ *Cassier's Magazine*, vol. xxxvii., No. 4, pp. 294-297.
§ Paper read before Appalachian Engineering Association, 1909 ; *Mines and Minerals*, Dec. 1909, vol. xxx., No. 5, pp. 269-270.

zinc carbonate. At Allisonia there has been discovered what may prove to be the largest zinc deposit in the Appalachian region. Large masses of blende are here found, mixed with only small quantities of iron pyrites. In 1908 there was no zinc ore reported mined in Virginia, but there was 1,410,961 pounds of spelter produced.

The zinc output of Tennessee was 688,149 pounds, which was three times the output of 1907.

Tin Prospects in Texas.—The location, extent, and geology of the tin deposits in Franklin Mountain near El Paso, Texas, is dealt with by R. Chauvenet.* The tin area is found wholly in the granite, an intrusive mass, which is coarse in texture and very deficient in mica, or indeed any of the minerals other than quartz and feldspar, which commonly characterise the rock. The granite is traversed by a number of dikes of pegmatitic contents which have been silicified at least near the surface, so that in certain places they have the appearance of quartz veins.

Cassiterite accompanies the quartz in these dikes, and is often disseminated in both quartz and pegmatite, but far more in the former. A very curious feature of the mineralisation is that it extends outside of the dikes into the surrounding granite. Very rich tin ore has been taken from the granite in numerous places. It will run from a mere trace up to solid chunks of almost pure oxide weighing several pounds. It is found that the mineral makes very little show at 2 per cent., while at 1 per cent. it has vanished, so far as the naked eye is concerned.

Experiments on the concentration of this ore have been made by different methods, a total saving of 90 per cent. was effected from the 1 per cent. ore giving a product assaying nearly 60 per cent. The freedom of all the ore from the ordinary impurities of tin ore has so far been remarkable, and is a feature of great practical value.

Tungsten in one sample of concentrates was present in the ratio of four parts of tungstic acid to 100 of cassiterite; in another sample it was reported lower, and in another as trace. Pyrites is practically absent; arsenic was twice reported absent, and twice as trace. All the heavy metals are absent.

Tungsten Deposits.—In a short article taken from the United States Geological Survey,† it is stated that tungsten is of wide occurrence, but the individual deposits are not large. As a rule they are " pockety "—that is, they occur in lenticular masses or small shoots. Many of these at the surface are quickly and easily mined, but it may then take all the profits derived from the first ore body to locate another one.

Zirconia in Brazil.—The important deposits of natural zirconia recently discovered and worked in São Paolo, Brazil, have been studied

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* *Mines and Minerals*, April 1910, vol. xxx., No. 9, pp. 529–531.
† *Ibid.*, Feb. 1910, No. 7, p. 387.

by L. Weiss * and R. Lehmann, and also by E. Wedekind.† This material appears likely to be of service in metallurgy on account of its highly refractory properties. The following analyses represent the denser portions of the deposit :—

			ZrO$_2$	Fe$_2$O$_3$	Al$_2$O$_3$	TiO$_2$	SiO$_2$	H$_2$O	Total.
			Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
I.	.	.	92·07	2·73	1·17	trace	2·73	0·88	99·58
II.	.	.	84·96	7·01	3·99	,,	1·57	1·04	98·57
III.	.	.	94·12	3·22	...	0·98	2·41	...	100·73
IV.	.	.	88·29	4·07	...	3·09	5·76	...	101·22

The purified zirconia may be fused in an arc, using 500 amperes or more, and then has the specific gravity 5·48 at 18°, and a coefficient of expansion of only 0·00000084, close to that of fused quartz. It may be moulded into crucibles by mixing with a small quantity of magnesia or fire-clay. Platinum may be rendered completely liquid, or quartz may be melted, in a zirconia crucible. The material is also highly resistant to reagents.

II.—*MECHANICAL PREPARATION.*

Concentration in the Joplin District.—The principles of ore concentration are dealt with,‡ and the methods used for the concentration of zinc ores in the Joplin district are described.

Electrostatic Concentration of Zinc.—L. A. Palmer § describes the methods used in the electrostatic separation of zinc. The separating of minerals by static electricity is comparatively new in the art of ore-dressing. In this process the separation depends upon the electrical conductivity of the minerals, some of which are good conductors, others partial conductors, and still others practically non-conductors. The Blake-Morscher machine is described and illustrated. In this machine the ore is fed into a double hopper, and passes to upper shaking feed plates ; these distribute the ore to upper charged poles, where the stream is split up by the static charge, the conductors being repelled and thrown out. The non-conductors or zinc products from the upper poles fall to the central hopper, and thence to the zinc separator. The Huff Electrostatic separator is also described and illustrated. In this machine a second stationary electrode is placed in close proximity to the roller, thus making an electrical field which may be varied greatly. The shaking plate of the Blake is eliminated.

* *Zeitschrift für anorganische Chemie*, 1909, vol. lxv. pp. 178–227.
† *Berichte der Deutschen chemischen Gesellschaft*, 1910, vol. xliii. pp. 290–297.
‡ *Mines and Minerals*, Jan. 1910, vol. **xxx.**, No. 6, pp. 383–384.
§ *Ibid.*, pp. 362–366.

Planilla Concentrator.—The Mexican " Planilla " concentrator is described and illustrated by H. J. Brown.*

This is one of the oldest of water concentrators, and may be built of native materials where required. It is most advantageously employed on ores not too high in iron, lead, and copper.

Pulp Classification and Tube-Mill Efficiency.—In an interesting paper presented to the Mexican Institute of Mining and Metallurgy, V. B. Sherrod † reports on some features of the extended research work carried out at the Guerrero Mill, Pachuca, Mexico. Special attention is called to the work of the Callow screens, which at a belt travel of 100 feet per minute, when equipped with 30-mesh screens, give an oversize, 92 per cent. of which remains on a 40-mesh laboratory screen, and 96·5 per cent. remains on a 60-mesh screen. At the same time an undersize containing practically all the liberated mineral is produced, 9·5 per cent. of which remains on a 40-mesh. Another interesting feature is the analysis of the product of the Chilian mills, 4 per cent. of which remains on a 40-mesh screen, and 32·4 per cent. of which passes a 200-mesh, notwithstanding that a 30-mesh "ton-cap" screen is used in the mills.

A special feature of the grinding at Guerrero Mill is the fineness of the tube-mill feed, 7 per cent. of which remains on a 60-screen. The conclusions drawn from tests on tube-mill practice are—(1) That the grinding efficiency increases with the percentage of solids in the feed up to approximately 55 to 60 per cent. ; (2) that the grinding efficiency increases with the quantity of ore fed per minute, up to a point which varies with the dimensions of the mill, and that beyond this point capacity is not gained, and within reasonable limits there is no loss except that due to the return to the mill of an excess of oversize.

Tube-Mill Circuit and Classification.—In view of the increased attention paid to classification for tube-milling purposes, G. O. Smart ‡ gives an account of the results of work done during the last year. For most efficient milling, it is necessary to maintain constant conditions as regards tonnage and moisture in the pulp entering the tube-mill, and the author describes how such a desirable uniformity of feed can be better secured than by the classifiers in common use in South Africa. Details are given of a tube-mill circuit with a single-cone classifier and diaphragm for each mill. A comparison is given of the work done in mills fitted with pyramidal spitzlutten and dewatering cones on the one hand, and single-cone classifiers with diaphragms on the other.

* *Mines and Minerals*, Jan. 1910, vol. xxx., No. 6, pp. 377–378.
† *Informes y Memorias del Instituto Mexicano de Minas y Metalurgia*, vol. i., No. 3, December 1909 ; *Metallurgical and Chemical Engineering*, March 1910, vol. viii., No. 3, pp. 139–143.
‡ *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, Feb. 1910, vol. x., No. 8, pp. 282–288.

Wet Concentration at Midvale, Utah.—The 400-ton concentrator of the United States Smelting Company is described by L. A. Palmer.* The ore treated averages 9 per cent. lead, 8 to 9 per cent. zinc, 13 to 14 per cent. iron, some copper, gold, and silver. The concentration products are two. The first contains lead, copper, gold, and silver values, from which the zinc has been so far removed that it does not interfere with the subsequent treatment in the blast-furnace; while the second product, that of zinc contains about 25 per cent. iron, the two being separated at the electrostatic plant (see Abstract, p. 250). Full details of the plant are given.

The concentration is effected on the basis of 1·83 tons of crude ore to 1 ton of concentrate. The extraction on the lead and zinc is 92 to 95 per cent., on the gold and silver 85 to 90 per cent., and on the copper about 80 per cent.

III.—*METALLURGICAL PREPARATION.*

Ore Dryer.—A novel type of dryer is described,† the fundamental idea of which is to bring into direct contact with the material to be dried a greater quantity of heated air than is possible with the ordinary form of rotary dryer. The cylinder consists of six curved sections held together by six channel irons running the entire length of the sections. In the channels are slotted openings for the admission of the heated air and gases.

Roasting.—W. S. Landis ‡ has determined the decomposition temperature of certain metallic sulphates by heating in a porcelain boat in a tube, the temperature of which was carefully regulated by means of a thermo-couple. As decomposition took place, the sulphur dioxide and sulphuric anhydride were passed into a bottle, and continually neutralised with dilute solution of caustic soda. The following results were obtained :—

Ferrous Sulphate.—The first traces of decomposition showed themselves at 550° C., the increase was but slight up to 580°, and then became more rapid until at 600° there was a sudden increase. On heating for two hours at this temperature all decomposition seemed to have stopped, as only very slight traces appeared on further heating to 650°, and no further traces beyond this to 960° C.

Copper Sulphate.—The first traces of acid appeared at 400° C. Only slight amounts were then noted up to 690°, when a very rapid evolution took place. A further trace was obtained at 700°, and then no more up to 900° C.

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* *Mines and Minerals*, April 1910, vol. xxx., No. 9, pp. 517–519.
† *Metallurgical and Chemical Engineering*, Feb. 1910, vol. viii., No. 2, pp. 107–109.
‡ *Ibid.*, Jan. 1910, vol. viii., No. 1, p. 22.

Zinc Sulphate.—The first traces of decomposition appeared at 730° C., more appearing at each increase of temperature up to 760°, when decomposition was very rapid. No further trace was found on further heating to 980°.

Treatment of Complex Ores.—The Malm dry chlorination process is described by R. L. Herrick.* This process is in reality a modification of older processes in which the best chemical features are combined and mechanical features are improved. The process consists in converting the complex metallic sulphides into chlorides by the use of dry chlorine between 60° and 70°, or in some cases at 100° C. This first chlorination in effected in a tube-mill through which chlorine gas is passed, and is followed by a wet treatment, the ore from the tube-mill being washed into a tank and agitated with steam and chlorine gas.

The resulting pulp may be treated in specially constructed filter-presses, and then the higher-priced metals in the solution are extracted by the substitution of cheaper ones thus—copper replaces gold and silver, lead replaces copper, and zinc replaces lead, leaving a zinc chloride solution, which is evaporated to dryness and electrolysed in the fused state, yielding pure zinc and liberating chlorine, which is used over again. The iron and manganese are removed from solution by the addition of zinc oxide in the presence of chlorine. In certain cases the whole of the metals are precipitated together by the use of zinc oxide and metallic zinc, and the sludge thus produced treated by a smelting operation.

* *Mines and Minerals*, Jan. 1910, vol. **xxx.**, No. 6, pp. 370–374.

EXTRACTION OF METALS.

CONTENTS.

I.—*ALUMINIUM.*

Production of Aluminium as a Laboratory Experiment.— B. Neumann * and H. Olsen point out that the production of aluminium on a laboratory scale is a very difficult matter ; they review attempts made by various workers, and give details of the method they have used in which the conditions of large-scale practice have been imitated as nearly as possible. Some useful details are given of the process used in large-scale practice, in which the aluminium cells are simple re-inforced rectangular wrought-iron boxes, on the bottom of which there is a series of carbon plates. The bottom plates act as a cathode at the start of electrolysis, the aluminium which is set free collects on the carbon plate and then acts itself as cathode. The cell is made so wide that the walls do not come into direct contact with the molten bath, but are completely covered with a layer of solidified charge. The size of the cell depends on the current. For a current of 8000 amperes the cells have a length of 4 feet 11 inches, a width of 3 feet 3 inches, and a height of 8 feet 6 inches. In each cell are six to twelve carbon anodes, which are suspended from insulated supports in double rows. Shorter electrodes are now used than were formerly employed.

The most suitable composition of the charge is 80 to 90 per cent. of cryolite and 10 to 20 per cent. alumina ; the purity of the raw materials is of great importance, iron and silica being especially deleterious. The mixture is fused by inserting between the carbon bottom and each anode a little rod of carbon and heating it to white incandescence. When the charge is molten, the carbon resisters are removed and the anodes are lowered into the bath. The temperature of the bath should be such that the colour is dark cherry-red. Crusts formed on the surface must be broken from time to time. The authors' laboratory scale experi-

ments were carried out in furnaces made of wrought-iron sheets, the bottom consisting of a plate of carbon. A direct current was used, 300 amperes at 14 volts, which could be converted into one of 150 amperes at 28 volts when necessary, this latter current being used to thoroughly fuse the bath when chilling was likely to occur. The most suitable design for the furnace was found to be a simple square box of 5 millimetres wrought-iron sheets welded at the edges, the bottom surface being 28 centimetres by 28 centimetres, and the height 19 centimetres. An Acheson graphite plate was fixed to the bottom 2·5 centimetres in thickness.

The anodes were carbon blocks about 14 by 14 centimetres in cross section. When melting a charge of cryolite and alumina care must be taken to have the carbons always covered with the mixture, during the melting ; a hard carbon resister 6 centimetres long and 1·6 centimetres diameter is inserted between anode and bottom plate and heated by the current to white incandescence. In this way the charge is slowly melted, $3\frac{1}{2}$ hours being required for 12 kilogrammes. In order to start electrolysis the anode is quickly raised, the carbon resister removed, and the anode suspended into the bath. If the anode has the correct temperature, electrolysis starts at once.

Full details of two experiments are given ; in one case trouble was experienced, while the other experiment was absolutely quiet.

II.—*COPPER.*

Copper Blast-Furnace Slags.—A. T. French * gives analyses of ten copper blast-furnace slags, and the results of the determination of their melting-points by means of Seger cones. The melting-points as obtained vary from 1230° to over 1350° C. It is shown that the slag with the highest melting-point has the lowest silica with high alumina, and the slag with the lowest alumina is the most fusible. It would seem from the results that a variation in magnesia from 5·5 to 1·5 per cent. produces little effect on the melting-point. Curves are given showing the relation between the per cent. of silica and the melting-point, and also between the per cent. of silica and alumina and the melting-point. The question as to whether alumina should be regarded as a base, an acid, partly base and partly acid, or as a neutral body which is held in solution or suspension in the fluid slag, producing a thickening effect, is discussed. In conclusion, it is stated that silica may vary from 40 to 47 per cent., ferrous oxide from 18·5 to 28·0 per cent., lime from 16 to 22 per cent., and alumina from 9 to 12·2 per cent., with very little change in the melting-point, but if these limits be passed either way, especially as regards silica and alumina, trouble will ensue.

Copper-Leaching Plant.—A copper-leaching plant for treating old dumps from the Gumeshevsky copper-mine, in the Ural Mountains, is

described and illustrated in detail by A. L. Simon.* From old data, it appears that in this mine a contact deposit between limestone and diorite has been worked, consisting of an extensive clay formation, in which occur irregular masses of various oxidised copper ores and boulders of limonite. The material, as mined, seems to have been hand-picked, and the old dumps, covering about 20 acres, with an average depth of 17 feet, contain from 10·98 to 33·18 lbs. of copper per cubic yard. Various other smaller dumps also exist, and altogether they are estimated to contain 7000 tons of copper.

Laboratory experiments showed that the copper could be partially extracted with a weak solution of sulphuric acid. A testing-plant was first erected, capable of treating 19 cubic yards of material at a time, and in this the technical and economical details were worked out. From this experimental plant the following information was obtained :—

1. One cubic yard of material yielded 12·78 pounds of copper ingots, an extraction of 56·25 per cent. of the copper being possible.

2. One cubic yard of material consumed 127·8 pounds sulphuric acid of 53° B.

3. $3\frac{1}{2}$ pounds cast iron were required to precipitate 1 pound of copper.

4. At a speed of 1000 gallons per hour, and with a surface of cast iron of 800 square feet, 95 per cent. of the copper in solution was precipitated.

5. Five days were required to go through the process, from the charging of the pans to running off the tailings.

6. One-third of the material was found to require grinding and two-thirds were sufficiently fine for leaching.

7. The consumption of acid was ascertained to be : 22·5 per cent. by copper, 49·9 per cent. by alumina, 12·4 per cent. by oxide of iron, 4·2 per cent. by lime, and 11·0 per cent. unaccounted for.

As a result of these investigations, it was decided to erect a plant capable of producing 392 tons of copper in a season of 150 days. The plant consists of a central power-station, mill, leaching tanks, precipitation tanks, &c. While the experiments were in progress a known deposit of iron pyrites was prospected, this being about four miles distant, and in places contained varying quantities of copper. An arrangement was made with a large sulphuric acid manufacturing firm, by which the latter was to erect a sulphuric acid factory and supply cheap acid for the plant, the price arranged being 17s. 9d. per ton of acid at 53° B. Only the pyrites containing copper is used, and the calcines are treated for the copper by roasting in a muffle furnace, with an addition of sulphuric acid at a temperature of from 450° to 550° C. in order to render the copper soluble. This copper is extracted by treatment with boiling water and dilute acid in lead-lined tanks, and precipitating at boiling temperature on cast iron.

The general arrangement of the plant is described in detail. The consistency of the pulp is about 2 parts water to 1 part dried tailings.

Each tank holds pulp containing 200 tons of dried tailings, and 132 tons of sulphuric acid are charged in. The pulp is agitated for nine hours. After the settlement of the slimes the clear solution is drawn off, and the slimes agitated three or four times with water to extract the copper liquors. The tanks are made of stones laid in live mortar, the sides and walls covered with a layer of concrete 4 inches thick, and this is protected by a layer of asphaltum 1 inch thick. The cupriferous solutions are conducted in wooden launders to the precipitation tanks, which consist of asphaltum covered concrete tanks. The upper tanks contain 110-120 tons of iron plates, and the three following tanks in each row each contain four inclined false-bottoms, each covered with about 3 tons of granulated pig iron in a layer 4 inches thick. Granulated pig iron is found to be a more convenient precipitant than iron in the shape of bars, plates, or scrap. Twelve tons of granules have the same precipitating capacity as 120 tons of plate. The cement copper, containing 60 to 75 per cent. copper, is smelted, with addition of white metal to blister copper which is refined.

Granby Smelter Equipment.

—B. L. Sackett [*] deals with the handling and treatment of the ore at the smelter of the Granby Consolidated Mining, Smelting, and Power Company, Ltd. This company carries out the mining, shipping, and smelting of 4000 to 5000 tons of copper ore per day, carrying about $1\frac{1}{4}$ per cent. of copper. Details are given of the ore bins, samplers, and blast-furnace charge-cars. There are eight blast-furnaces, the principal dimensions of which are given in the following table :—

	Nos. 5 and 6.	Nos. 1, 2, 3, 4, 7, and 8.
Dimensions at tuyeres . . .	48 in. × 260 in.	44 in. × $266\frac{1}{2}$ in.
Furnace floor to feed floor . .	18 ft.	18 ft.
Centre of tuyeres to feed floor . .	12 ft. 10 in.	12 ft. 10 in.
Bottom of crucible to feed floor .	15 ft. 8 in.	15 ft. 8 in.
Diameter of tuyeres . . .	$3\frac{1}{2}$ in.	5 in.
Number of tuyeres to one jacket .	6	3

These furnaces receive 313 cubic feet of air per square foot of hearth area per minute. They differ only slightly in the respective amounts of ore handled. At present a fair average may be called about 7 tons of ore smelted per square foot of hearth area, per twenty-four hours. With all eight furnaces running, the daily tonnage is 4500 to 4800.

The blast-furnace work is very simple on account of the nature and composition of the ores treated ; they require no addition of iron ore or lime as flux, the following being an average analysis over three months :—

Copper, 1·24 ; insoluble, 40 ; iron, 12 ; lime, 16·7 ; sulphur, 3 per cent. A large percentage of the sulphur volatilises as SO_2, and practically all the remainder combines with the iron and copper to form a matte ;

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[*] *Mines and Minerals*, April 1910, vol. xxx., No. 9, pp. 524–528.

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thus the ore furnishes no heat for its smelting by the burning of its own sulphur, and coke has to be used to about 12 per cent. of the ore smelted, the amount varying slightly according to the slag run. An average analysis of the matte produced gave 35·6 per cent. copper, the slag being as follows :—Gold, 0·005 ounces per ton ; copper, 0·22 per cent. ; silica, 44·8 per cent. ; iron, 16 per cent. ; lime, 21 per cent.

The flue dust is collected, mixed with water, briquetted, and the briquets charged into the blast-furnace green, no binder being used. Some details are also given of the converter department and the power and machinery equipment.

Oil-Burner in Reverberatory Furnaces.—R. L. Herrick [*] describes the use of oil in reverberatory furnace practice at Cananea. A detailed drawing of the Kittle oil-burner is given.

Refining Process.—An elaborate study of the elimination of impurities during the refining of copper in the reverberatory furnace has been made by W. Wanjukoff,[†] a charge of 2 tons being employed for the experiments. Samples of the charge were withdrawn from time to time, cast into ingots, and sampled by means of a planing machine. Both chemical analyses and microscopical examinations were made. The temperature of the bath falls to 1094° just before boiling, but then rises to 1123°. The composition of the flue gases is an accurate indication of the course of the reaction, and curves are given expressing the variations. Iron is mostly oxidised in the early stages, cobalt being the most rapidly removed after iron. Nickel, on the other hand, is not removed until after most of the iron and cobalt has been oxidised. From the commencement of the poling process the nickel remains constant, the quantity in this case being 0·11 per cent. Sulphur is oxidised after iron, cobalt, and nickel, proceeding very rapidly. The sulphur dioxide formed is first dissolved and then given up, causing the boiling of the charge. The oxidation of sulphur by dissolved oxide is still observed during the poling. The percentage of oxygen increases rapidly up to the end of the boiling stage, and then falls rapidly as poling proceeds. At the end of the first refining the oxygen amounts to 0·23 per cent. In the second refining, the oxygen content again rises and falls, and is finally brought down to 0·04 per cent. by the addition of phosphorus. Lead is removed during the oxidising stage of both the first and second refining ; silver accompanies lead. The elimination of arsenic and antimony is hindered during the first refining by the presence of slag, although a part is carried off during the boiling stage. The second refining is necessary for the removal of arsenic and antimony. These reactions may be followed by means of the microscope.

Washoe Copper Reduction Works in 1909.—An interesting article appears,[‡] comparing the practice of the Washoe Reduction Works in 1909

* *Mines and Minerals*, Jan. 1910, vol. xxx., No. 6, pp. 367–368.
† *Metallurgie*, 1909, vol. vi. pp. 749–759, 792–801.
‡ *Mines and Minerals*, April 1910, vol. xxx., No. 9, pp. 520–523.

with the practice in the same works as described in previous descriptive articles in the same journal 1904 and 1907. The capacity of the smelter in tons of ore treated per day has more than doubled since 1904, an average of 10,000 tons of ore being treated every twenty-four hours, with proportional increases in the amount of lime, coke, &c. Since the shut-down of the winter 1907–1908, due to the unsettled condition of the copper market, a vigorous campaign has been instituted to reduce all costs to a minimum. In the concentrator department steam has been supplanted by electricity, heavier crushers are used, and the Huntington mills for finest grinding have been enlarged from 5 feet to 6 feet. In winter, wet ores are apt to freeze, and cannot be dumped from the cars. To overcome this a thawing-shed is used, heated by a fire-box at each end, the flues passing below and between two tracks of rails to a stack in the middle. This shed holds twenty-four 50-ton cars, which remain in for twenty-four hours for thawing. In the blast-furnace department special attention is now paid to stopping air-leaks in the mains, bustle-pipes, and tuyeres, as it is realised that such leaks may reach a surprising proportion of the total volume from the blower. Considerable reduction of coke has been obtained by increasing the amount of sulphides in the charge, by adding coarse concentrates, and also fine concentrates in the form of briquettes. The increase in sulphur in the charge from 8 or 9 per cent. to 11 or 12 per cent. has resulted in a reduction of the coke used from $10\frac{1}{2}$ to 9 per cent. Since May 1909 a second-class Butte ore has been used in the converter department for lining the converters. Before that time a highly siliceous ore containing 85 per cent. silica, with low sulphur and iron, was used for lining, a mixture of 2·9 tons of this ore to 1 ton of slime being employed ; this material gave a life of about six charges of $7\frac{1}{2}$ tons of 45 per cent. copper matte per lining. The second-class ore now used runs about 60 per cent. silica, gives an efficiency of slightly under 90 per cent. of the other, showing a life of $5\frac{1}{4}$ charges of matte per lining.

The converters as now constructed are 8 feet by 12 feet 6 inches. The two ends of the converters were formerly made of sheet steel, but now a steel casting is used. The converters are also equipped with all the improvements of the last few years, including the individual Repath tuyeres, the high joint between cap and body, heavier cast-steel angles and cast-steel rails. The proper lining of converters requires a good deal of experience, and the time required for lining is about $1\frac{1}{2}$ hours per converter. The weight of the lining is about 16 tons, and that of the converter and lining 42 tons. The various departments of the smelter are treated as separate and distinct in the matter of costs. Records are kept of material entering and leaving, and expense incurred by any department, such as assaying, is apportioned back to it. The samples entering the laboratory for analysis may be roughly divided into ores and the resulting products.

The smelter products number about forty—*i.e.* concentrates, slimes, and tailings from the concentrator ; calcines, calcine barrings, flue-dust, &c., from the roasters ; matte, slag, &c., from the reverberatories ; matte, slag, flue-dust, &c., from the blast-furnaces ; slag, cleanings, anode copper,

&c., from the converters; in addition to the main flue-dust, linings for converters, &c.

All samples of tailings, slag, matte, anode copper, ores, calcines, concentrates, &c., are analysed daily for those elements necessary for the economic working of the plant. Other elements in the same or other products may be determined from weekly samples made from the dailies by representative weight. Full analysis is made of monthly samples of everything handled by the smelter, and these are made up from the daily and weekly samples. The scheme for handling the work in the laboratory is to give each man a definite and constant amount of work as near as possible of the same kind.

In apportioning the cost of assaying to each department, a scheme of normals is used. One normal is made equal to the cost of one colourimetric copper determination. A determination of the insolubles, or iron or sulphur in ore, is each equal to two normals. A silica fusion equals three normals. A coal or coke analysis equals twelve normals, &c.

The laboratory staff numbers one head chemist and ten assistants, the total number of normals for one month has been over 50,000.

III.—*GOLD.*

Precipitating Effect of Substances containing various forms of Carbon and Cellulose on Cyanide Solutions containing Gold and Silver.—A. J. Clark * and W. J. Sharwood give the results of a series of experiments made by the authors at the Homestake Mine, together with other information on the subject gathered from various sources. Experiments were conducted on the relative activity of various substances by stirring vigorously 5 grammes of each precipitant with 300 cubic centimetres of solution containing gold to the value of $2·63 per ton, with the following results :—

	Percentage of Gold precipitated.
Graphite (Dixon's flake)	0·0
Bituminous coal (40 mesh)	7·0
Coke (40 mesh)	19·6
Charcoal pine (40 mesh)	27·0
Calcium carbide	5·0
Zinc dust	99·3

Experiments were also conducted on the effect of wood ashes containing a small proportion of charcoal on the cyanide extraction of gold from tailings containing pyrites. The result of these experiments were as follows :—

Percentage of Ashes added to Tailings.	Percentage of Gold extracted by Cyanide.
0·17	52·8
0·8	46·0
1·73	35·8
8·0	3·5

These illustrate the deleterious effect of small quantities of carbonaceous matter remaining in an ore which has been subjected to a preliminary roasting operation.

Results are given of the examination of floating rubbish, consisting of charcoal, charred pieces of wood, clean chips and twigs, and particles of coke which were skimmed from the surface of cyanide solution in a slime agitator vat; these were found to contain considerable amounts of precious metals.

Several writers have published experimental results showing a large decomposition of cyanide and also a considerable precipitation of precious metals due to contact with wood, canvas, cocoanut-matting, and other fabrics used as filters, all forms of cellulose, and the authors give results obtained by examination of various materials that had been exposed to gold and silver bearing solutions for considerable periods; these showed only comparatively small quantities of precious metals. A bibliography is added on literature relating to charcoal as a precipitant for gold.

Rotary Extractor for Precious Metals from Solution.—Zinc shavings have frequently been subjected to mechanical motion whilst in contact with gold and silver cyanide solutions, and some success has been achieved, but mechanical difficulties have developed, due to the method of applying motion. W. D'Arcy Lloyd * and E. T. Rand describe a machine they have constructed, which consists of rotating compartments covered with a water-tight casing of light steel-plate. The solution enters a steady head tank, passes into the hollow shaft, and passes through perforations into the first compartment, then to a settlement tank and through the second compartment; in this case it passes through the zinc, then through the perforations in the shaft to the third chamber. The rotor revolves from one to one and a half times per minute. All gold slime loosened from the zinc passes to the tank beneath. The advantages claimed for this method are :—(1) Ready access to slimes, enabling a daily clean-up to be made if necessary without stoppage of precipitation. (2) With chippings and coarsely cut filiform zinc, absence of breaking down and readiness of removal of adhering gold in an acid bath without consumption of all the zinc, with a consequent saving of zinc and acid. (3) Clean up quick and cleanly, with a consequent advantage of minimum loss. (4) Shortness of time rotor is out of action during dressing. (5) No fouling of zinc. (6) While in action, no danger of theft of gold slimes ; and (7) (added in discussion by A. F. Crosse) the mechanical driving off of hydrogen bubbles from the zinc, this aiding precipitation.

IV.—*LEAD*.

Blast-Furnace Practice at Midvale, Utah. — The general smelting practice at these works is described by L. A. Palmer.† There

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* *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, Dec. 1909, vol. x., No. 6, pp. 201–204.

† *Mines and Minerals*, April 1910, vol. xxx., No. 9, pp. 543-544.

are six lead furnaces each having a capacity of 200 tons of ore and flux per day besides fuel. Each furnace is 45 inches by 160 inches at the tuyeres, widening to 132 inches by 160 inches at the shaft. The crucible is elliptical in shape. There are two water-jackets to each side, and one on each end. Each side is provided with ten $3\frac{1}{2}$-inch tuyeres with individual valves and all metal connections to the 18-inch bustle pipe which supplies air at 30 to 40 ounces. The furnaces are tapped through an Arents syphon to ordinary lead pots, these are wheeled to the bullion house and dumped to the melting kettles. A dry dross, consisting chiefly of copper, is first skimmed off, and then the temperature is lowered and a wet dross of antimony and arsenic is skimmed. The drosses are charged to the sweating furnace, the lead sweated out, and the dross returned to the blast-furnace. The lead bullion is drawn from the melting kettles through iron syphon pipes to the moulds, in which it is cast into anodes. The slag from the furnace is tapped to a rectangular forehearth, from which the matte is tapped from the bottom. An average analysis of the slag shows silica, 37 per cent.; ferrous oxide, 27 per cent.; lime, 22 per cent.; zinc oxide, 6 per cent.; lead, 0·5 to 0·75 per cent. The common matte from the blast-furnace averages copper, 7 to 10 per cent.; lead, 12 to 15 per cent.; iron, 21 to 23 per cent.; sulphur, 21 to 23 per cent. This is enriched to a matte carrying 40 per cent. copper by one or more furnace treatments then charged into a reverberatory furnace for the production of white metal and a slag assaying lead, 17 per cent.; silica, 39 per cent.; iron, 23 per cent. This slag is returned to the blast-furnace, and the white metal is sent to the copper refinery.

Elimination of Smelter Fume.—In a general article by L. A. Palmer * on the elimination of smelter fume, full details are given as to how difficulties arising from fume have been overcome by the United States Smelting Company. In these works a modification of "pot" or converter" roasting is used for the lead ores, but it has been proved that the matte from the blast-furnaces cannot be treated so successfully in converter roasters as in hand-rabbled reverberatory furnaces. The chief difficulty in fume elimination is due to the presence of sulphuric anhydride in the gases from the roasters, this on reaching the atmosphere is converted into sulphuric acid by the absorption of moisture. The roaster fume is therefore neutralised by means of zinc oxide fume before being passed to the bag-house. For this purpose a brick furnace, fired with coal placed over lime-rock and a small amount of zinc concentrate, is made to discharge its fume into the brick flue, where it mingles with the roaster gases. Air is blown into this furnace, and under the influence of the blast the zinc sulphide rapidly oxidises and passes into the flue, where it meets the roaster gases charged with sulphuric anhydride and neutralises them with the formation of zinc sulphate. The fumes from the blast-furnaces are passed direct to the bag-houses. The ideal temperature for blast-furnace gases at the bag-house is 70° C., and it must not exceed

* *Mines and Minerals*, March 1910, vol. xxx., No. 8, pp. 496–499.

90° C. ; the ideal temperature for roaster gases is 100° C., and the safety limit is reached at 120° C. The dust which is removed from the bags is retreated, the roaster fume going back to the roasters, and the blast-furnace fume to the arsenic plant, where the arsenic is extracted and refined.

Lead Free from Gold and Silver.—In a paper on the detection of minute traces of gold in country rock, A. R. Andrew * discusses the difficulties met with in the attempt to obtain lead and lead compounds absolutely free from gold and silver. Samples of pure red-lead and litharge, extra pure carbonate, pure and specially pure acetate were examined, and all found to contain precious metals. The pure acetate, for instance, gave beads representing 0·057 grains, and 0·009 grains of gold per ton. Various methods were used by the author for the preparation of pure litharge, these included Stas' method by the electrolytic precipitation of the impurities from an aqueous solution of lead acetate, the precipitation of the lead as sulphate, its conversion into carbonate, and thence to oxide or metal ; Tate's method by the fractional reduction of a portion of the lead oxide by melting with cream of tartar, and the author's method of carrying on this fractional reduction in thick clay scorifiers. From all these experiments the lead obtained was found to contain minute quantities of gold, and the author concludes that it is impossible at present to obtain litharge or any salt of lead absolutely free from gold and silver in sufficient quantities for the assay of country rock.

V.—*RARE METALS*.

Platinum.—According to F. A. McDermott,† platinum black may be very conveniently prepared by the reduction of platinum chloride in solution with sheet aluminium. The product is pure and finely divided, and does not contain aluminium. When zinc is used, the precipitate always contains zinc.

Titanium.—G. H. Stanley ‡ gives an account of experiments carried out on the smelting of titaniferous iron ores in crucibles. A table is given showing amounts of material taken, nature and analysis of slags, yield of iron, and temperature used.

The preparation and properties of metallic titanium have been studied by L. Weiss § and H. Kaiser. The purest powdered metal is obtained by double reduction of potassium titanium fluoride with sodium, but even this only yields a product containing 86 per cent. titanium, the remainder being principally oxygen and iron. The product obtained by

* *Bulletin of the Institution of Mining and Metallurgy*, No. 64, January 13, 1910.
† *Journal of the American Chemical Society*, 1910, vol. xxxii. pp. 336–338.
‡ *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, vol. x., No. 5, pp. 162-172.
§ *Zeitschrift für anorganische Chemie*, 1910, vol. lxv. pp. 345-402.

reduction with aluminium has the approximate composition Al_3Ti_2. Compact titanium, prepared by electrical fusion of the powder or of the aluminide in a vacuum, contains 97 per cent. titanium, and has the specific gravity 5·17, and specific heat 0·1418. A technical fused product was found to contain 92·45 per cent. titanium, 0·35 per cent. aluminium, 3·35 per cent. iron, 2·78 per cent. silicon, and 0·78 per cent. oxygen.

Another study of the reduction of titanium by M. A. Hunter [*] led to the conclusion that only very impure metal could be obtained from the double fluoride. Small quantities of very pure metal (99 per cent. titanium) may be obtained by heating titanium tetrachloride with sodium in a closed steel bomb, the reaction being explosive. The pure metal forms beads, which may be forged into rods at a red heat. The specific gravity is 4·50, and the melting-point between 1800° and 1850°.

Tungsten.—The preparation of tungsten from wolframite has been investigated by L. Weiss. [†] The reduction by means of aluminium is very violent, but by using an insufficient quantity of aluminium a product containing 90·7 per cent. of tungsten may be obtained. A purer product is obtained by fusing the wolframite with calcium carbonate and calcium chloride, precipitating the tungstic acid by means of an acid, and electrolysing it after mixing with cryolite. The temperature of the bath may be still further raised by the addition of alumina, the liberated aluminium acting as a reducing agent towards a further quantity of tungstic acid. The metal thus prepared forms small globules. Metal containing as much as 98·96 per cent. tungsten is obtained by fusing tungsten trisulphide with lime in an arc furnace with a crucible of Acheson graphite. After fusing the pure metal in a hydrogen vacuum it is white and fairly malleable, having a specific gravity 18·72 at 20°, and hardness 6·5 to 7·5. It is very inert towards reagents, and assumes temper colours like steel when heated in air.

Zirconium.—Metallic zirconium has also been studied by L. Weiss [‡] and E. Neumann. Either sodium or aluminium may be used to reduce potassium zirconium fluoride. The best metal is obtained by reducing so as to obtain an alloy with aluminium, and then heating this in a vacuum furnace in an atmosphere of nitrogen. The aluminium is thus distilled off, and the metal remaining, containing 99·8 per cent. zirconium, has a specific gravity 6·40 at 18°, and hardness 7·8. It resembles cast iron in appearance.

VI.—*TIN.*

Chinese Tin Smelting.—W. F. Collins [§] gives an account of the production of tin in the province of Yunnan, China. The whole industry

[*] *Journal of the American Chemical Society*, 1910, vol. xxxii. pp. 330–336.
[†] *Zeitschrift für anorganische Chemie*, 1910, vol. lxv. pp. 279–340.
[‡] *Ibid.*, pp. 248-278.
[§] *Bulletin of the Institution of Mining and Metallurgy*, No. 53, December 1909.

is in the hands of the Chinese, and the methods used are extremely primitive. There are now about 30,000 men engaged in the mining, concentration, and reduction of the ore, and after refining, the greater part of the metal comes to Europe. The deposits now worked are all of alluvial origin, the deeper deposits being much the richer. The tinstone, which is usually of sand-grain size, occurs in highly ferruginous bedded deposits. The underground ores usually contain a little magnetite, and as much as 55 per cent. of hæmatite. There is always present a small amount of lead. A preliminary concentration is carried out in reservoirs and ponds, and the concentrates so obtained are further treated in rectangular brick-lined buddles. The concentrates are smelted in charcoal furnaces, of which drawings are given in the paper. The output of each furnace is 12 to 15 slabs of 110 catties (1 catty = 1·33 lb. avoir.) per day. The furnaces are generally only in full working during November, December, and January. They are built of brick, and are simple structures. The blast is supplied by a wooden air-pump, with piston packed with feathers. The slags from the furnaces are crushed and washed to extract the metallics, the remainder is re-smelted with ore until considered free from tin. The chief impurities in the tin are iron, often present up to 1 per cent., and lead, usually less than 0·25 per cent., though the metal from some of the mines may contain over 50 per cent. lead. Practically all the tin is exported to Hong-Kong, where the greater part is refined by Chinese merchants for European consumption. In an appendix to the paper legal points relating to mining in China are given, and also details of weights and measures of the Mengtsz district.

VII.—*SILVER.*

Silver Cyanide Mill.—An illustrated description of the silver mill of the San Rafael y Anexas Company, Pachuca, is given by E. Girault.[*] The ores treated contain from 70 to 75 per cent. silica, and from 10 to 20 per cent. limestone. The silver, mixed with a small amount of base sulphides, is found mostly in the state of Ag_2S. All ores containing above 300 grammes of silver to the ton are cyanided. The ores are first hand-picked, then crushed in Blake crushers and sampled in the mine yard; the material is ground in cyanide solution containing about 0·25 per cent. potassium cyanide, and the alkalinity of this solution is kept at 1 kilo-gramme of lime to the ton. The stamp-battery pulp is concentrated on Wilfley tables, and the tailings are classified in Dorr classifiers, re-ground in Krupp tube-mills, fitted with Neal's baffle at both ends and El Oro liners, then settled in Dorr pulp thickeners, agitated in Pachuca pneumatic tanks, the charge containing 100 tons of dry slime to 120 tons of solution. The solutions are filtered in Moore vacuum filters, and precipitated on zinc shavings 0·006 inch thick. The precipitate is pressed, dried to 20 per cent. moisture, and melted with 15 per cent. broken glass,

6 per cent. borax, and 4 per cent. sodium carbonate. The short zinc which remains on a 20-mesh screen is returned to the boxes, while the shorts on 40-mesh screen are melted, with 20 per cent. broken glass, 8 per cent. borax, and 6 per cent. sodium carbonate. The slags formed are crushed quarterly in a battery and concentrated on a Wilfley table, the concentrates being melted and the tails treated in the cyanide tank or sold.*

VIII.—*ZINC.*

Retort-charging Machines.—O. Saeger † describes new charging and discharging machines for zinc retorts. The ordinary type of zinc retort is used, and the charging machine, which is electrically worked, travels on rails in front of the furnaces. Tubes fitted with screw conveyors enter the retorts, distributing the charge very uniformly by completing the charging as they are being withdrawn. These movements are automatic. The present machines charge six retorts, in two vertical sets of three, at once. The discharging machines are similar in construction, spiral conveyers being used to rake out the charge. The machines are in use at the Bernardhütte, in Rosdzin, O.S. It is found that a range of 120 muffles (forming one side of the furnace) can be charged in thirty minutes and discharged in twenty minutes. The exposure of the workmen to excessive heat and fumes is also avoided.

Influence of Iron.—The fact that zinc is more readily extracted from calcined calamine than from roasted blende is explained by Lindt ‡ as being due to the influence of iron. If iron is present, a part of the zinc oxide is fixed to form the compound Fe_2ZnO_4, which is less readily reduced than ZnO. It is therefore desirable to remove iron as far as possible before reduction. The same author § has determined the loss of zinc caused by the presence of lime and magnesia, which are converted into sulphates during roasting, and react with a part of the zinc oxide, converting it into sulphate during the distillation process. Lime and magnesia may be removed before roasting by washing with sulphurous acid. In place of costly washing towers the author proposes to conduct the process together with the ore-washing, using sulphurous acid instead of water.

Electrolytic Zinc.—The electrolytic processes for the production of zinc are reviewed by V. Engelhardt‖ and M. Huth, who show that the chloride processes have proved unremunerative, whilst practical difficulties have hitherto stood in the way of a successful sulphate electrolysis, of which the want of a satisfactory anode is the chief. Ferchland's lead

peroxide anodes have been employed for a year in Upper Silesia, giving zinc containing only 0·01 to 0·02 per cent. impurities. The power consumption is 3900 kilowatt-hours per metric ton of zinc. Siemens' and Halske's manganese dioxide anodes are still more resistant, and have the advantage that they can be prepared in the form of plates, whilst lead peroxide can only be formed into rods. The method is most economically applicable to poor zinc ores or to residues containing zinc.

ELECTRO-METALLURGY.

CONTENTS.

I.—*ELECTRIC SMELTING.*

Electric Smelting of Copper.—S. B. Ladd * draws attention to the fact that little has been done in the application of the electric furnace to copper smelting. As an accessory to a matte-smelting blast-furnace or reverberatory, electric smelting is capable of being employed to advantage in many cases. It is suggested to arrange that the smelting by fuel heat may proceed to a point where there will be formed a semi-fluid mass capable of flowing and forming a bath, when the completion of the smelting will be done by electric heat. The electrical heating of the bath in a matte-smelter will permit of the cutting down of the coke charge to the point where the coke will do the smelting of the more fusible material and the electric current the balance. This should be secured by a hearth of a trough character with electrode terminals, and also a fore-hearth with a flowing tap, so as to maintain in the hearth a bath of constant level. A current of high amperage and low voltage should be used. The adaptation of electric smelting to reverberatory practice calls for a new type of furnace, one in which there can be maintained two long banks of ore or charge with a trough between, this trough having electrode pockets or connections at both ends, and a fore-hearth with a flowing tap. It is pointed out that in a reverberatory furnace a large amount of waste heat is available for current generation, and thus the entire heat energy can be utilised either primarily as fuel heat or secondarily as electric heat.

Electric Smelting of Copper Ores.—W. Wolkoff † reports on some experiments on the electric smelting of copper ores. A sulphide ore was used containing 8·20 per cent. of copper, with acid gangue. By the addition of 6·2 per cent. of hammer scale a good fusion could be obtained,

using 350 amperes at 90 volts for an hour, with 12 kilogrammes of ore. Practically the whole of the copper was obtained in the matte, the slag only retaining 0·15 per cent. However, the matte was not homogeneous, the lower layers containing free metal. Very little gas was evolved. The conversion of the ore into a 60 to 70 per cent. matte required, on this small scale, 4·9 electrical horse-power-years per ton of copper. Previous experience has shown that the consumption on the large scale is only one-fourth or one-fifth of that in the laboratory. This is confirmed by results obtained in the Héroult and Keller works, indicating a power consumption of 1·2 electrical horse-power-years per ton.

By smelting 10 kilogrammes of ore with 1·25 kilogrammes of roasted matte, using 400 amperes at 75 volts for thirty minutes, 96 per cent. of the copper was extracted.

The complete process :—

(1) Electric smelting of ore to matte ;
(2) Dead roasting matte ;
(3) Electric smelting of the roasted matte with a second quantity of ore ;
(4) Refining the copper ;

represents a great simplification of the copper-smelting process. The power consumption for the electrical part of the process seems likely to be, on the large scale, about 1·6 horse-power-years per ton of copper.

II.—*ELECTRIC FURNACES*.

Chilling and Heating Action of Electrodes.—C. Hering [*] considers the choice which may sometimes arise in determining the correct proportions of furnace electrodes, as to whether the electrode loss shall be allowed slightly to chill or heat the product in the furnace, as either may be adopted at the sacrifice of the other. The variations of the conductivities of various electrode materials with the temperature is the cause of this possibility. The subject is treated analytically and mathematically, and it is shown that with an electrode material such as carbon, having a decreasing resistivity for an increase of temperature, the total loss may be diminished, if desired, by making the section somewhat larger than that required for no flow of furnace heat with an attendant chilling of the furnace. With materials which have a rising resistivity with increase of temperature, such as iron, the total loss of heat may be reduced by decreasing the section of the electrode. A minimum loss is obtained in each case, however, with a section of certain size. The greater the change of resistivity with temperature, the greater will be the reduction of power loss possible by operating at a minimum loss with neither chilling nor heating effect from the electrode heat. The author concludes that, in general, the corrections due to differences in electrical resistivity and thermal conductivity of electrode materials are

too small to be considered in practice, and that the engineer need only make the section a little larger for materials with a falling resistivity, and a little smaller for materials with a rising resistivity.

Electrode Conductivities.—A new method for measuring the mean thermal and electrical conductivities of electrodes is given by C. Hering.* The object is to find the mean conductivities to be used in determining the best ratio of length and cross-section of an electrode. A rod of electrode material to be tested is embedded in a heat-insulating material, except at its ends, which are water-jacketed. A large current is passed which will raise the temperature of the embedded part ; a pyrometer is introduced in the middle, which is the hottest part. When the pyrometer indicates that the highest temperature has been reached, the temperature of centre and water cooled ends, the current and the voltage are measured. The product of the current and the voltage gives the heat flow in watts, which is leaving at the two terminals. The heat conductivity is determined from the following formula :—

$$k = 0 \cdot 02986 \frac{\text{WL}}{\text{TS}}$$

in which k is the mean heat conductivity in gramme calories per second per square inch for $1° \text{C}$. per inch ; L, length of embedded part in inches ; T, the difference in temperature between middle and ends ; and S is the cross-section of the rod in square inches.

The mean electrical resistance for the range of temperature used is obtained by the formula :—

$$r = \frac{\text{ES}}{\text{CL}}$$

in which E = volts, and C = amperes.

J. Forssell,† in a paper on current densities and energy losses in electrodes, gives a theoretical analysis of the different factors influencing the energy losses in electric furnace electrodes. It is pointed out that the value of this analysis extends far beyond the interpretation of the special case given. The paper contains many mathematical calculations, and is unsuitable for a brief abstract.

Electrode Design.—C. Hering‡ points out that for the calculation of the proportions of furnace electrodes the rules hitherto used are entirely inadequate and incorrect. These rules have been based on such factors as the allowable current densities, least practicable resistance, lowest heat conduction, heat losses, &c. The fundamental principle of the author's analysis of this problem is that the heat gradient at the hot end should be zero ; this can be obtained only when the temperature of

* *Transactions of the American Electrochemical Society*, 1909, vol. xvi. pp. 317–329 ; *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No 12, p. 514.
† *Metallurgical and Chemical Engineering*, Jan. 1910, vol. viii., No. 1, pp. 26–33.
‡ *Proceedings of the American Institute of Electrical Engineers*, 1910, vol. xxix. pp. 285–334.

the hot end is equal to that of the furnace. Current density as a basis of electrode design is condemned, as also is the usual rule of making the resistance as low as possible. The resistance for the most economical working is fixed by the temperature, current, and material. Formerly an attempt was made to keep the outside terminals as cool as possible ; it is stated that they should be so designed as to get as hot as possible. Electrodes should also be made as small as possible. The author considers that the desirable qualities of electrodes do not depend on their thermal or electric conductivities alone, but on certain relations between the two. These qualities as a basis of proportioning electrodes have been abandoned by the author, and two new measures of electrode qualities are used—viz. "electrode voltage" and "specific cross-section." Experimental work is described on the valuable properties of graphite, carbon, iron, and copper as electrode materials, and tables and curves are given illustrating the results. The following is a summary of the chief results :—

Current.—Results show that at 1500° C. a graphite electrode will carry over three times as much current as a carbon electrode of the same size ; iron will carry over twice as much as graphite, and nearly seven times as much as carbon ; the current capacity of copper is about forty-five times that of carbon and fourteen times that of graphite.

Watts.—For all four materials, the watts increase nearly in proportion to the temperature.

Electrical Resistivity.—At 1400° C. the relative values were found to be—copper, 1 ; iron, 10 ; graphite, 72 ; carbon, 340.

Thermal Conductivity.—These values differ far less than the electrical resistivities, the relative values at 1400° C. being about—copper, 1 ; graphite, 0·34 ; iron, 0·22 ; carbon, 0·17.

Electrode Voltage.—Iron is found to be nearly as good as copper, and much better than graphite, the relative values at 1400° C. being about—copper, 1 ; iron, 1·5 ; graphite, 5 ; carbon, 7·5.

Specific Section.—At 1400° C. the relative values are approximately as follows—copper, 1 ; iron, 6·6 ; graphite, 14·6 ; carbon, 45.

Actual Losses and Sizes.—The losses at 1400° C. are in the same ratio as electrode voltage, and sizes in same ratio as the specific sections.

Electrode Losses.—C. A. Hansen * gives an analysis of the electrode losses in one of his furnaces with a view of finding out how far these losses are determinable from published data, and to see what conditions affect them. The resistances of graphite and carbon electrodes are given, and also the effect of firing the electrodes at temperatures from 1200° to 3500°. Other matters treated in the paper include the effective length of electrodes, contact resistance between water-jacket and electrode, resistivity of graphite, and heat conductivity.

E. F. Roeber * also deals with furnace electrode losses. He investigates from a theoretical and mathematical standpoint how far the assumption of constant thermal and electric conductivities hold good in practice.

III.—*ELECTRO-REFINING.*

Electrolyte Conductivity.—J. W. Richards † and W. S. Landis discuss, in a paper read before the American Electrochemical Society, October 1909, the actual conductance of the electrolyte in electrolytic refining tanks as the same are ordinarily set up and operated. It is shown that a maximum conductance is reached after a given depth for electrolytes and metals, and it is useless to increase the depth of electrolyte underneath or at the sides of the electrodes past a certain point.

Electrolytic Copper Refining.—Power is an important item in the cost of electrolytically refining copper, and W. L. Spalding ‡ discusses this matter in an interesting paper read before the American Electrochemical Society in October 1909. The cost of power per ton of copper refined is less than in many electrochemical industries, since with soluble anodes the voltage power is used in overcoming the resistance of the electrolyte and metallic circuit, and meets with no opposing E.M.F. from the decomposition of the electrolyte. Nevertheless the power cost reaches 40 per cent. of the total cost of refining. In securing cheaper power the following considerations should be taken into account. First, the unchanging resistance and the continuity of the process allow a constant load, day and night; secondly, waste-heat boilers on reverberatories and cupolas furnish considerable power at little expense, although they have a disadvantage in being irregular. The most economical methods of using electric power for refining are considered under various conditions.

Electric Furnace for Copper Refining.—The electric furnace, writes G. von Rauschenplat,§ may be used with advantage in the refining of copper. Experiments with an arc furnace show that a slag consisting essentially of cupric ferrite, CuO, Fe_2O_3, melts at $1450°$ to $1500°$. The electrodes in the bath are of copper, connected with a water-cooling arrangement which does not project into the bath. The removal of sulphur depends on the quantity of copper oxide in the slag; if this is low, sulphur is only very slowly removed. A ferrite slag acts more energetically than a silicate, probably on account of its higher temperature. Lead, on the other hand, is much more readily

eliminated by a silicate slag. Arsenic is only eliminated after most of the other impurities have been oxidised. Iron is very readily removed by both kinds of slag. Electric smelting, using roasted matte as the slag, with the addition of silica if necessary, gives less loss than ordinary refining. As the impurities are not completely removed by one passage of the metal through the slag, even when the layer of the latter is deep, an arrangement of several electric furnaces is proposed, in which the crude metal first passes through a used slag, and then through fresh slags, so that the impurities are ultimately concentrated in a small bulk of slag.

Gold Refining by Electrolysis.—A recent modification of the Wohlwill process of refining gold by electrolysis, which broadens greatly the scope and applicability of the original process, is described,* and deserves attention, owing to its possible usefulness beyond the sphere of gold refining. When gold, rich in silver, is refined in a solution of gold chloride containing hydrochloric acid or other chlorides, it becomes necessary to remove mechanically, from time to time, the layer of silver chloride which forms on the anode; in practice this becomes necessary when the silver present reaches 6 per cent. If this layer is not removed, chlorine is set free, which introduces complications. A novel arrangement by which these difficulties are overcome is the use of a superposed alternating current upon the direct current used. This may be obtained by connecting a direct-current dynamo in series with an alternating-current dynamo. As long as the voltage of the latter is lower than that of the former, the current obtained will always have the same direction, but will change periodically from a minimum to a maximum. It is preferable, however, to use an alternator with a higher maximum voltage than the direct-current dynamo in series with it. The electrolytic effect is equal to the effect of the direct current alone. The voltage at the terminals of the refining cell is less than when direct current only is used, and it is possible to increase the anodic current density without causing the liberation of chlorine. When refining gold containing 10 per cent. of silver, according to the original Wohlwill process, an anodic current density of not more than 750 amperes per square metre must be used, and it is found necessary to scrape off the silver chloride from the anode every forty-five minutes. When using an alternating current also, it is possible to maintain an anodic direct-current density of 1250 amperes per square metre without any necessity of scraping off the silver chloride.

Alloys much richer in silver may also be treated by this method. Much less gold is found to pass into the slimes. When a current density of over 1000 amperes is not necessary, the amount of free hydrochloric acid may be less, and with 3 per cent. hydrochloric acid, it is no longer necessary to heat the electrolyte as in the original process.

Nickel Recovery.—Some nickel salts are made at a New Jersey refinery from electrolytic solutions obtained in the refining of copper.†

* *Metallurgical and Chemical Engineering*, Feb. 1910, vol. viii., No. 2, pp. 82, 83.
† *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No. 12, p. 543.

During the refining, the nickel in the anodes goes into solution in the electrolyte, and unless the solutions are changed before the amount of nickel reaches 1 per cent. of the solution, nickel is deposited with the copper. It is said that this causes the copper to lose some of its toughness and electrical conductivity.

IV.—*ELECTRO-DEPOSITION.*

Deposition of Metals from Acetone Solutions.—H. E. Patten * and W. R. Mott describe experimental results on the deposition of some metals from acetone solutions. Saturated solutions in acetone were electrolysed between platinum electrodes to ascertain whether the metals would deposit or not ; and if so, at what current density and cathode polarisation.

The following is a summary of this preliminary work :—

1. Sodium and strontium metals have been deposited from saturated solutions of the iodides in acetone at room temperature and high-current density.

2. Cadmium, tin, antimony, bismuth, and arsenic have been deposited from solutions of their chlorides in acetone at moderately low-current density.

3. Iron and copper were deposited from solutions of their chlorides (·ic) in acetone at rather high-current densities.

* *Chemical News*, vol. c., No. 2614, pp. 319–321.

THE PROPERTIES OF METALS AND ALLOYS.

CONTENTS.

I.—*COMMON METALS.*

Aluminium.—Aluminium is volatile in a vacuum at or above 1100°, but if the heating is performed in a porcelain vessel, the volatilisation is found by E. Kohn-Abrest [*] to cease after a time, owing to the coating of the residue with a layer of aluminium silicide, formed by the reduction of the porcelain by the metal.

Arsenical Copper.—The relative value of nickel and arsenic as materials to be alloyed with copper for the manufacture of fire-box plates and stays is discussed by C. Heckmann.[†] Figures are produced to prove the uniform quality of arsenical copper plates, and it is maintained that arsenic is not lost by volatilisation during use in the fire-box. Arsenical copper has the advantage that poling may be carried further than with ordinary copper, thus ensuring the complete removal of oxide. The presence of a few tenths per cent. of nickel is advantageous. On the other hand, W. Stahl [‡] states that the mechanical properties of the nickel alloy are always better than those of arsenical copper, and considers that the preference shown by railways for arsenical copper is only due to an insufficient acquaintance with the nickel alloy. A further reply by C. Heckmann [§] refers to occasional brittle specimens of arsenical copper, which are to be referred in all cases to errors in manufacture.

Antimony.—R. C. Palmer,[||] in a paper read before the American Electrochemical Society, October 1909, describes a new electrolytic

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[*] *Comptes rendus*, 1910, vol. cl. pp. 169–173. [†] *Metallurgie*, 1909, vol. vi. pp. 760–761.
[‡] *Ibid.*, 1910, vol. vii. pp. 14–16.   [§] *Ibid.*, pp. 163–164.
[||] *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No. 12, p. 521.

method for the preparation of explosive antimony. A history of the production of explosive antimony is given, and experiments are described on the electrolysis of non-aqueous solutions of antimony trichloride. Acetone was found to be a suitable solvent. The deposit has the characteristic flaky appearance.

The Microscopic Examination of Zinc.—The effect on the microscopic structure of zinc caused by small quantities of iron, lead, cadmium, arsenic, antimony, tin, bismuth, and copper has been studied, and the melting-points of such alloys have been determined by T. Arnemann.* The thermal results agree in the main with those of other investigators. The softer alloys are difficult to polish in the ordinary manner, and good surfaces are obtained by fusing on a flat surface of carbon (pure carbon crucible).

Iron produces distinct crystals of the solid solution characteristic of hard zinc from 0·06 per cent. iron onwards. One per cent. of lead is clearly visible. Cadmium is visible in the form of a eutectic from 1 per cent. onwards, and it is probable that solid solutions are formed below that limit. Even 0·1 per cent. of arsenic or antimony may be detected microscopically, whilst 2 per cent. is required to produce a marked effect on the melting-point. The tin eutectic is also visible when the quantity of added metal is as low as 0·1 per cent., and the same is true of bismuth. Copper forms solid solutions up to a limit of 2·5 per cent. The method is very suitable for determining the purity of commercial zinc.

Pure Copper Castings.—In his description of the manufacture of pure copper castings, W. J. Reardon † says that a few years ago founders considered it impossible to make castings of pure copper. The casting of copper tuyeres for blast-furnaces has been done for many years. This copper, however, is not pure—phosphorus and other elements have been added in small quantities. He describes the method of moulding, &c., he used for the production of a cylinder of cast copper, which with gates and risers weighed about 2½ tons. The copper was melted in oil furnaces without crucibles. When melted the metal was "poled" with hickory poles to bring it up to "pitch." Samples were taken at intervals and tested in a vise for density and toughness. When the copper proved to be of the proper "pitch" it was withdrawn from the furnaces by pouring into a large ladle. Twelve pounds of silicon-copper of 10 per cent. silicon was then added as a further deoxidiser, and the casting then poured. Two castings were made, and when turned and finished did not show any shrinkage or spongy spots. The most essential condition in casting pure copper is so to proportion the gate that the shrinkage will take place in the gate and risers. The mould and method of gating are very important factors. He does not favour the pouring of pure copper for sand castings at a low temperature. The copper must be poured hot to ensure sound castings.

* *Metallurgie*, vol. vii. pp. 201–211.   † *Metal Industry*, vol. ii., No. 1, p. 4.

II.—RARE METALS.

Metallic Filaments for Lamps.—A. Stewart * gives a series of articles on the use of rare metals and earths in the art of illumination. The following table give the temperatures which emit visible light rays :—

	Degrees Centigrade.
Just glowing in the dark	525
Dark red	700
Cherry-red	908
Orange	1150
White	1300
Dazzling white	1500
Probable temperature reached in the electric furnace	3500
Probable temperature of the sun	6500

Tables are also given showing the chemical and physical properties of artificial illuminants, and of the rare metals and their ores used. An interesting account is given of the manufacture and varieties of metallic filament lamps.

Observations on the Tellurides.—V. Leuber † has collected historical and other details known of the tellurides. Tellurium itself has found little application in the arts or industries, and in metallurgy thus far no valuable properties have been found for the element or its alloys. Full details are given of the occurrence of tellurides, and various laboratory experiments are described on methods of analysis, synthesis, and various methods of decomposition. A study of the reactions of tellurium and selenium, with special reference to the tellurium minerals, includes their reactions on gold and silver solutions. Tellurium is found to reduce gold from solutions, and gold tellurides also precipitate gold from chloride solutions.

The action of various reagents on the tellurides is considered. These reagents, including permanganate and bichromate of potash, and ferric chloride, with ferric chloride, tellurium is dissolved, the iron being reduced to ferrous chloride ; this reaction has been used for the extraction of tellurium. The behaviour of various tellurides to heat in various gases is also discussed. It is also pointed out that tellurium can be transported in nature as an alkaline tellurite or tellurate.

Titanium.—W. S. Weedon ‡ gives results of an investigation of a large number of elements, compounds, and mixtures with considerable variation of preliminary treatment, as to their suitability for arc-lamp electrodes. No materials were found to give as high an efficiency in candle-power per watt as those that contained the element titanium. The titanium arc is suitably formed between a titanium carbide cathode below a copper anode. The latter is inactive, and does not waste

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* *Engineering Review*, vol. xxii., No. 2, pp. 75–78 ; No. 3, pp. 150–153 ; No. 4, pp. 231–234.

† *Economic Geology*, Oct. 1909, vol. iv., No. 6.

‡ Paper read before the American Electrochemical Society, October 1909 ; *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No. 12, p. 509.

appreciably. The titanium arc is a flame arc, and its efficiency increases with increase in current density and with increase in arc length.

The method of manufacture of the titanium-carbide electrodes is given. For this the lump material is coarsely powdered and then pulverised to a fine state. It is then worked up with oil, glycerine, or other suitable binder, and extruded through a nozzle by means of a hydraulic press. After drying at ordinary temperatures the sticks are finally dried in a gas oven, and then fired at a high temperature, preferably in an electric furnace of the carbon-tube type. The material used for the manufacture was prepared in an electric furnace by the reduction of rutile.

III.—*ALLOYS*.

Aluminium-Bronze.—E. S. Sperry * states that, unlike the tin bronzes, there is no tendency for the aluminium to segregate, nor do they crystallise like the brasses or other alloys of copper containing zinc. Thousands of small pins of cast aluminium-bronze (10·5 per cent. aluminium) have been used by the United States Government in the Springfield rifle. These pins, called "firing pins," were used for firing the cartridges because steel would not stand. The greatest obstacle in the way of casting aluminium-bronze is its oxidation when melted. Whenever the surface of the molten metal is exposed to the air, a film of oxide of aluminium forms on it. The more it is exposed, the greater the amount. When allowed to remain at rest in a crucible, very little forms, as the surface of the metal is protected by the film already on it. This explains why aluminium-bronze should always be poured with as little stirring as possible. Any agent, such as wet sand, which tends to stir the metal up, produces dross and the accompanying dirty castings. The more quietly the metal can be poured, the better the castings. One mixture of aluminium-bronze seems to cast as well as another. There is no addition that can be made to overcome the dross formation, nor will any flux obviate it. While dross is the greatest obstacle encountered in casting these bronzes, it may be said that shrinkage is the next. By the use of sufficiently large risers and freedom from sharp corners in the casting, with an ample gate, shrinkage may be readily overcome. Aluminium-bronze works hot even better than copper, as it is softer while at a red heat. At the same time, it is not black short like the copper and zinc alloys. While the colour of aluminium-bronze is attractive, it is not to this property that it owes its value, but to its strength, homogeneity, and freedom from crystallisation.

Aluminium-Zinc Alloys—Tensile Strength.—W. D. Bancroft,† in a paper presented at the Cincinnati Convention of the American Brassfounders' Association, gives much useful information regarding

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* *Mechanical Engineer*, vol. xxv., No. 630, p. 206.
† *Ibid.*, No. 634, p. 329.

the tensile strength of aluminium-zinc alloys. The aluminium used was about 99·9 per cent. pure. The zinc was "Bertha Pure Zinc," which contained not over 0·2 per cent. impurities. On account of the great affinity of aluminium for silicon, pure graphite crucibles were used. Most of the difficulties of the investigation were met with in casting. The alloys at the zinc end of the series developed the coarse crystalline structure characteristic of commercial zinc. Castings of the same composition did not always give the same crystalline structure, even when cast under apparently the same conditions. To obtain castings of fine crystal grain, the well-known process of crystal inoculation was tried. The metal was poured into the mould when very mobile, and then at the moment of solidification a piece of finely crystalline-rolled zinc was thrust down into the centre. Another expedient attempted in order to avoid cooling and promote rapid freezing was to agitate the mould during the freezing process. Rocking, tapping, and stirring were also tried, but, like the inoculation process, were unsuccessful. The method finally adopted was to pour the metal into an ice-cold mould at a temperature as near the freezing-point as possible. As was anticipated from Shepherd's equilibrium diagram, the results show that the alloys may be divided into three groups. With the introduction of zinc to aluminium the tensile strength gradually rises to 15·5 tons per square inch at 30·0 per cent. zinc. There is then a steady fall to 11·0 tons with 96 per cent. zinc, and with further additions the decrease in strength is very rapid. The ductility of aluminium is lowered by zinc, falling to 5·0 per cent. when 10 per cent. of zinc is present. All alloys containing more than 10 per cent. of zinc give approximately the same ductility, namely, about 2·5 per cent.

Amalgams.—The zinc amalgams have been investigated by E. Cohen [*] and K. Inouye by means of solubility determinations. A special apparatus for filtering the liquid amalgam from the solid residue at any given temperature is described. The solubility is found to increase regularly from 0° to 100°. This result does not agree with Puschin's thermal analysis of the amalgams, but the authors consider the determination of solubility to be more trustworthy.

A few amalgams of silver have been prepared by the action of finely divided silver on mercuric chloride by H. Chapman Jones.[†] They are denser than a mixture of the components. The amalgam containing atomic proportions of silver and mercury is homogeneous, and has the density 12·81 at 20°.

Cobalt Alloys.—F. Ducelliez [‡] records that determinations of the electro-motive force of a number of alloys of cobalt, normal cobalt sulphate being used as the electrolyte, and both cobalt and the other component metal being employed as the comparison electrodes. The results indicate that cobalt does not form a compound with copper, bismuth, or

* *Zeitschrift für physikalische Chemie*, 1910, vol. lxxi. pp. 625–635.
† *Transactions of the Chemical Society*, 1910, vol. xclvii. pp. 336–339.
‡ *Bulletin de la Société Chimique*, 1910 [iv.], vol. vii. pp. 196–206.

lead. Solid solutions are formed to a limited extent with copper. In the cobalt-antimony series the compound CoSb is clearly indicated, and in the cobalt-tin series the effect of the compound CoSn is also very clearly marked.

Cobalt-Gold Alloys.—The alloys of gold with cobalt have been studied for the first time by W. Wahl.* The freezing-point curve is of a simple type, consisting of two branches, intersecting at a eutectic point at 997°. Each metal retains about 5 per cent. of the other in solid solution. The colour of the alloys is intermediate between those of the component metals. The magnetic properties fall at first rapidly, and then more slowly, with increasing amounts of gold. The great tendency of cobalt to remain undercooled during freezing is also manifested in its alloys.

Copper-Aluminium-Manganese Alloys.—W. Rosenhain † and F. C. A. H. Lantsberry contribute an account of researches on the properties of some alloys of copper, aluminium, and manganese. These researches constitute a continuation of the previous work by Professor H. C. H. Carpenter and C. A. Edwards on the alloys of copper and aluminium as recorded in the Eighth Report. The authors have limited their investigations to those regions of the system where results of practical interest were to be anticipated. As regards the heavy alloys, consisting principally of copper, important results were to be sought only in alloys containing more than 85 per cent. of copper; while at the aluminium end of the series only alloys containing more than 95 per cent. of aluminium could be expected to yield results of practical value. The study of the constitution has been extended beyond these limits in order to render the data over the "useful" range more intelligible. The report includes a model of the "liquidus" of the ternary system of alloys, containing less than 11 per cent. of aluminium and less than 10 per cent. of manganese. The well-marked minimum of the copper-aluminium series, occurring at about 8·5 per cent. of aluminium, is continued in the ternary system in the form of a valley in the liquidus surface. A study of the microstructures has shown that alloys on the copper side of this valley are homogeneous, while those to the left are duplex. A comparison of the model with the mechanical properties of the alloys further indicates that in the ternary alloys, just as in the binary copper-aluminium series, the presence of the second phase to the left of the minimum renders the alloys stiffer, stronger, and less ductile. No new constituent resulting from the presence of manganese was detected in the alloys at the copper corner of the series. This result is of special interest, because some of these alloys are distinctly magnetic. If the magnetic properties of these alloys are due to the existence of a magnetic metallic compound, this compound must be soluble in either or both the constituents found in these alloys.

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxvi. pp. 60–72.
† *Ninth Report to the Alloys Research Committee of the Institution of Mechanical Engineers.*

As regards alloys at the light end of the series, the introduction of manganese is found to give rise to the formation of a definite compound, Al_3Mn, which tends to make the alloys hard and brittle. If present in large proportions this compound appears to undergo a gradual change, which leads to the spontaneous disintegration of the alloys containing it. An ingot consisting of 65 per cent. aluminium and 35 per cent. manganese is a hard metallic mass when first cast, but falls to a fine crystalline powder in the course of a few hours, and this process appears to be independent of oxidation. In the "useful" light alloys of the ternary system this disintegration does not occur. The authors suggest that alloys of copper with aluminium alone are generally contaminated with a certain proportion of alumina, formed when the aluminium is added to the molten copper containing more or less oxygen ; by the previous addition of manganese the formation of this alumina is inhibited and the properties of the resulting alloy are improved. A small percentage of manganese renders the alloys more ductile without reducing their ultimate stress, while larger proportions of manganese increase the strength but lessen the ductility of the alloys. Sand castings giving an ultimate strength of 36 tons per square inch, with an elongation of 22·5 per cent. on 2 inches, have been obtained ; while in the form of rolled bars the best of the heavy alloys reach an ultimate strength of 43 tons per square inch, with 22 per cent. elongation. In the hard-drawn condition one of these alloys gave an ultimate strength of 52 tons per square inch, with 10 per cent. elongation.

A result of considerable importance was obtained by means of abrasion tests on certain of the heavy alloys ; the test applied was one of simple wear against hardened steel rollers, the loss of weight being determined. The best of these alloys possess a very great resistance to wear of this kind, far surpassing even the harder varieties of steel. These alloys also possess a great power of resisting corrosion, both by fresh- and sea-water, while tests made upon them at temperatures up to 500° C. indicate that they retain their strength up to 300° C.

The properties of the ternary alloys containing more than 95 per cent. of aluminium are little better than those of copper-aluminium alloys. The presence of manganese, however, appears to protect these alloys from corrosion. The report is accompanied by sixteen plates containing ninety-two photo-micrographs.

Iron-Copper Alloys.—C. F. Burgess * and J. Aston have examined the properties of iron-copper alloys. Alloys up to 2 per cent. copper forge well at red heats. Those from 2 to 7 per cent. will not forge at a low heat, and rather poorly at white heat, the ease of workability varying inversely as the percentage of copper. From 7 to 75 or 80 per cent. the alloys may be classed as non-forgable. Between 80 and 100 per cent. they will forge at a fair red heat, but not at a normal forging heat for iron. No segregation has been detected in the alloys. Tensile tests

are given of the alloys containing up to 7 per cent. copper in an unannealed and an annealed condition, and compared with nickel steels.

The same authors, in a supplementary paper * to the above, deal with the magnetic and electrical properties of the same iron-copper series. Tests were made upon twenty-four binary alloys of iron and copper, and upon twenty-one alloys with copper-silicon, copper-aluminium, copper-tin, and copper-arsenic. Above 2 per cent. of copper the permeability falls off rather quickly as the copper content is increased, but only bars of 4 per cent. and more are conspicuously poor. The bar containing 94·34 per cent. copper is non-magnetic. Annealing at 675° greatly improves the quality of all the bars. Among the bars made with alloy additions, nothing of high quality was indicated. Summarising, it may be said there is no advantage to be gained in adding copper to iron if a good magnetic permeability is required. The quality deteriorates almost in proportion to the added copper content. On the other hand, it may be said that there is nothing to be feared from the effect upon the magnetic quality of the small percentages of copper ordinarily found in commercial steels. Results are given of electrical resistance tests, in which the resistance rises to a maximum of 17 microhms per cubic centimetre at a copper content of 1·51 per cent.

Iron-Nickel Alloys.—The magnetic and electrical properties of iron-nickel alloys have been examined by C. F. Burgess † and J. Aston on a series of alloys in which the impurities have been kept down to the lowest possible point. The magnetic tests were made upon a Eaterline permeameter on the specimens containing from 0·27 to 75·06 per cent. of nickel in an unannealed state, and also after annealing at 675° C. and 1000° C., and quenching at 900° C. In the unannealed state, up to 1·93 per cent. nickel, the magnetic properties are little inferior to electrolytic iron. Additions of nickel cause a falling off in quality, until at 22·11 per cent. they are very poor, and with 25·20 per cent., 26·4 per cent., and 28·42 per cent. nickel they are non-magnetic. Further increases of nickel, 35·09 per cent., 49·08 per cent., and 75·06 per cent., restored the magnetic properties very markedly, the maximum values being obtained with 47·08 per cent. Annealing at 675° has resulted in general in an improvement of magnetic quality. Annealing at 1000° for the bars with smaller nickel content resulted in an increase of permeability for lower magnetising forces, and bars containing 25·2 per cent. and 26·4 per cent. nickel became appreciably magnetic. Hysteresis curves were taken on the alloys showing higher permeability, and it was found that the 50 per cent. nickel alloy had the lowest loss. The electrical resistance was also determined, and it was found that there was a gradual increase of resistance with increase of nickel up to 22·11 per cent., after which there was a sudden rise at compositions corresponding to those of the non-magnetic alloys. Beyond about 30 per cent. nickel a decrease is noticed, giving a curve similar to that on the other side of

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the maximum range. It is suggested that the maximum point might correspond to the compound Fe_2Ni.

"Monel Metal" Flux.—When melting Monel metal* clay-lined crucibles must be used, and when charged covered with a lid. No flux, charcoal, or other material should be added to the metal while melting. The liquid metal can be raised to a high temperature without injury. When the crucible is taken out of the furnace about $1\frac{1}{2}$ ounces of magnesium should be added to every 100 pounds of the liquid metal. The magnesium may be placed in a "retainer" or in tongs, pushed to the bottom of the crucible as quickly as possible and carefully stirred. The metal can be cast in dry or green sand moulds, on the same general plan as casting manganese bronze, but as the melting-point of "Monel metal" is higher, the sand selected should be of a drier nature the higher the temperature. Liberal risers should be supplied to the casting.

Nickel-Carbon Alloys.—Alloys of nickel and carbon, containing only 0·2 to 0·6 per cent. of iron, have been examined by K. Friedrich † and A. Leroux. Nickel holds up to 1 per cent. of carbon in solid solution, and there is a eutectic point at 2 to 2·5 per cent. carbon, and 1307° to 1318°. An alloy containing 2·6 per cent. carbon contains primary crystals of the second constituent, the nature of which could not be determined. The alloy containing 1 per cent. carbon is so brittle as to be broken by a hammer, but alloys containing larger quantities of carbon are so tough as to need a planing machine for cutting the sections.

Nickel-Copper Alloys. — E. Vigouroux ‡ states that the study of the action of reagents on alloys of nickel and copper, as well as the measurement of the electromotive force of such alloys in nickel sulphate solutions, indicate that these metals do not form a compound with one another.

Tin-Bronze Corrosion.—The corrosion of tin-bronzes by acid solutions is found by F. Giolitti § and O. Ceccarelli to depend on their microscopic structure. The simultaneous presence of two solid solutions accelerates corrosion, and inequalities in the composition of the margin and centres of crystals of solid solutions also tend to accelerate corrosion. It is thus possible to predict the resistance of a bronze to corrosion from a microscopical examination.

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* *Metal Industry*, vol. ii., No. 1, p. 19.
† *Metallurgie*, 1910, vol. vii. pp. 10–13.
‡ *Bulletin de la Société Chimique*, 1910 [iv.], vol. vii. pp. 191–196.
§ *Gazzetta*, 1909, vol. xxxix., ii. pp. 557–575.

IV.—*MISCELLANEOUS.*

Calcium as a Deoxidiser.—J. Horton * states that calcium is now coming largely into use as a deoxidiser in the casting of German silver. The deoxidising agent mostly used for the last forty years has been magnesium. Magnesium, however, has the disadvantage as compared with calcium, that it does not consistently produce a sound casting. It has a tendency to unite with the alloy, and has to be used in larger quantities. Manufacturers find the use of calcium to be conducive not only to efficiency, but also to economy, owing to the great diminution in the risk of producing bad castings.

Calcium is used chiefly in the form of an aluminium-calcium alloy.† Its great value lies in removing the gases which are occluded in metals. Among such gases are hydrogen, nitrogen, and carbon monoxide.

Electro-Cementation.—A. Sang,‡ in a paper read before the American Electrochemical Society in October 1909, describes the process of electro-cementising as applied to wires and strips. In this process the wire to be coated with zinc is slowly passed through a furnace charged with crushed coal and oxide of zinc. The wire is heated by means of an alternating current. The wire is quickly brought to a cherry-red heat, at which temperature all grease is volatilised, scale or rust is reduced by the carbon, and occluded gases are driven out; at the same time the zinc oxide in immediate contact is reduced, and as vapour soaks into the pores of the metal. As the wire returns through the upper part of the furnace it cools slowly from a point well above it recalescence, so that it is well annealed. The coating obtained is of the colour of freshly deposited silver, and the iron wire which has absorbed an almost infinitesimal amount of zinc by being exposed to zinc vapour in a reducing atmosphere resists corrosion in a remarkable manner. Compared with sherardising, the electro-cementising process is said to have a better heat efficiency. The process does not seem to have been used on a commercial scale.

Erosion of Bronze Propellers.—The erosion of bronze propellers in high-speed steamships is stated § to vary largely under apparently identical conditions, and its investigation is somewhat difficult in consequence. The primary cause appears to be due to the filing action of the water when the propeller is travelling at high velocities, but the fact that the maximum amount of erosion seldom occurs at the tip of the blades, where the helical velocity is greatest, shows that secondary causes enter largely into the action. Investigations by Silberrad have shown that dirt in the castings has little to do in causing erosion, and since there is no increase in the copper concentration in the eroded areas, there can be no galvanic action.

* *Metal Industry*, vol. ii., No. 3, p. 107.　　　　† *Ibid.*, p. 108.
‡ *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No. 12, pp. 532–533.
§ *Engineering*, Jan. 14, 1910, vol. lxxxix. p. 54.

The new turbine alloy introduced by Parsons, which has been tried on the *Mauretania* with great success, showing no signs of erosion after six months' hard steaming, has the following properties compared with the older standard bronze :—

	Parsons' Bronze.	Standard Bronze.
Elastic limit (tons per square inch) . .	18	16–18
Ultimate stress ,, ,, . .	33–34	33–34
Elongation (per cent.)	12–15	12–20
Brinell hardness number	131	...
Time required to produce standard erosion under standard conditions . . .	117,200 hours.	29,700 hours.

Metallic Concrete.—A new industrial process is suggested by K. Friedrich,[*] consisting in the preparation of masses of the character of concrete, the pebbles being represented by some inert material and the cement mortar by a fusible alloy. For instance, an alloy of lead and antimony is melted and cooled, and whilst still plastic, iron filings are incorporated with it. Bearing metals can thus be made in which the cheaper iron replaces the hard constituents generally employed. Again, an alloy of 90 per cent. tin and 10 per cent. copper is melted, and between 450° and 220°, when the mass is plastic, fragments of a blue cobalt glass are kneaded in. On cutting and polishing, the glass is seen in a metallic matrix. Many ornamental products can thus be prepared, using alloys of gold and silver with various stones, &c. Various applications are proposed.

Rolling-Mills.—The question of electrical drive for rolling-mills is considered by A. S. McAllister.[†] The simplest method of adapting electric motors to rolling-mill service is to substitute for each steam-engine previously used a motor of equivalent maximum horse-power and install a generating equipment suitable for supplying energy to the motors. A simple method for decreasing the cost of the generating equipment is to install a storage battery with regulating devices for causing the generators to charge the battery when the load on the system is light, and for allowing the battery to discharge into the system when the load is heavy. When the older steam-engine practice is followed, the rolling-mill motors must be of the reversing type, and must be capable of accelerating quickly to full speed. This requires the use of motors of the direct-current type, which are much superior to alternating-current motors for variable speed and reverse-motion services. For the direct driving of non-reversing rolling-mills, no motor is better adapted than the polyphase induction machine. This motor has no commutator, and hence cannot spark.

The relative advantages of electrochemical and mechanical energy

[*] *Metallurgie*, 1910, vol. vii. pp. 97–99.
[†] *Metallurgical and Chemical Engineering*, Feb. 1910, vol. viii., No. 2, pp. 75–76.

storage are compared, the two devices used being storage battery or the fly-wheel. The chief advantage of the fly-wheel resides in its ability to deliver its stored energy at practically any rate demanded; where a limited amount of energy is to be used for a short time at a very high rate, the fly-wheel is much less expensive and more satisfactory than the storage battery; but where a considerable amount of energy is to be stored for use at a relatively low rate, the battery is far preferable to the fly-wheel.

Miscellaneous.—The properties of pure boron have so far been unknown, since the only material heretofore produced and alleged to be pure boron has been in the form of an amorphous powder. E. Weintraub * gives results of an experimental research, the object of which was to produce pure boron in a fused homogeneous form, and which formed part of a research for elements suitable for incandescent filaments. The author was assisted in this work by E. Kraus and G. Weintraub. The reactions between boric anhydride and magnesium are first considered.

It was found that by carrying out the reaction at a high temperature, in a large gas muffle or an electric furnace, boron could be obtained containing only 0·11 per cent. magnesium boride as against 3 to 4 per cent. when the reaction is carried out in the old way. The resulting mass, however, always contained oxygen as suboxide of boron.

It is interesting to note that around 2500° magnesium oxide is reduced by boron, whilst at 1600° boron anhydride is reduced by magnesium. Experiments were next carried out on the reduction of boron chloride by means of hydrogen, and this was the method finally adopted for the production of pure boron. The method consisted of running one or more alternating current arcs, in a mixture of gaseous boron chloride and an excess of hydrogen, in a glass or copper vessel, copper electrodes being used. The boron thus reduced is partly thrown off in the form of fine powder, and partly settles on the ends of the electrodes, where it forms small rods. After a while the arc runs between two boron electrodes, and the rods melt down to boron beads. These fused lumps analysed 99·8 to 100·2 per cent. boron. The boron powder can be purified and melted down by two methods developed during this investigation for the melting down of refractory materials without contamination with foreign materials. The first consists in the use of a mercury arc either in vacuum or in an indifferent gas, and is best applied to materials having an appreciably high conductivity. It is based on the evolution of heat at the anode of a mercury arc, and on the fact that materials such as tungsten, tantalum, boron, &c., have no affinity for mercury. The second method is based on the use of a high potential arc in an indifferent gas, and is especially useful to the treatment, melting, and purification of substances having only a slight conductivity. The physical properties of pure boron are next considered; the melting-point and sublimation point lie near together—between 2000° and 2500° C.

The considerable vapour tension of boron, which begins to show itself in blackening the walls of an exhausted globe at 1600°, make it unsuitable for incandescent filaments.

In hardness, fused boron is inferior only to diamond. Its fracture is conchoidal, showing no sign of micro-crystalline structure. The electrical conductivity of fused boron is the most interesting property. At ordinary temperature boron is a very poor conductor, but its conductivity rises with the temperature in a remarkable manner. Between 23° and dull redness its conductivity increases about two million times. The effect of dissolved carbon in boron is considered, and it is pointed out that between pure boron and boron containing 8 per cent. carbon there is a most interesting series in which almost any desired negative temperature coefficient of resistance can be selected. The effect of traces of boron on carbon is to change the negative temperature coefficient of the carbon into a positive one, and thus to metallise it.

V.—*PHYSICAL PROPERTIES.*

Atomic Volume Determinations.—A method of determining the atomic volume of substances at very low temperatures has been devised by E. Cohen * and J. Olie, who have applied it to the two allotropic forms of tin and of carbon. Pure graphite after compression has a density 2·216 at 18°, which increases to 2·223 at − 163·5, whilst diamond increases over the same range from 3·514 to 3·519. White tin increases from 7·285 to 7·350, and grey tin from 5·751 to 5·768. There is therefore no foundation for the suggestion that allotropic modifications tend towards the same atomic volume at very low temperatures.

Metastability of Metals.—In the first of a series of papers, entitled "The Metastability of our Metal World," it is shown by E. Cohen † and K. Inouye that cold-worked metals are generally in a metastable state, and tend to return to the more stable crystalline condition. A piece of metal, rendered crystalline by etching, is pressed against a clean piece of the rolled metal, and is kept at or above 100°. The strained metal is gradually rendered crystalline by the contact. This effect is observed with tin, lead, and bismuth. Crystalline lead does not produce any change in rolled zinc. Cold-pressed articles, such as the brass reservoirs of oil-lamps, are in a state of strain, and are found to exhibit a peculiar pitting, due to recrystallisation, after a time, especially if kept in a warm room. Microscopical examination shows that the structure has changed from that of a worked metal to that of one recrystallised by annealing. A similar instance is described from the lead sheeting of a sulphuric acid chamber.

Oxy-Acetylene Cutting.—An interesting application of the oxy-acetylene torch for cutting metal is illustrated.‡ This application con-

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* *Zeitschrift für physikalische Chemie*, 1910, vol. lxxi. pp. 385–400.
† *Ibid.*, pp. 301–311.
‡ *Metallurgical and Chemical Engineering*, March 1910, vol. viii., No. 3, p. 164.

sists of cutting holes 13 feet in circumference in the steel piling of the new permanent intake well for the Chester (Pa.) water-supply system.

Shrinkage.—The shrinkage of metals and alloys during cooling in the mould has been measured by F. Wüst,[*] using an apparatus in which the changes in length of a bar are transmitted to pistons which displace water in a graduated tube, lever connections being thus avoided. A cooling curve is taken simultaneously, the results being plotted as a curve connecting length with temperature. The total shrinkage is, in most metals and alloys, less than that calculated from the coefficient of expansion. Alloys consisting of aggregates, such as those of lead and antimony, shrink less than their components, whilst the brasses, bronzes, &c., containing solid solutions, shrink more than the metals of which they are composed. An alloy of 49·88 per cent. bismuth, 32·47 per cent. lead, and 17·38 per cent. tin expands during cooling, so that the bar finally obtained is 0·3 per cent. longer than the pattern.

Solubility of Gases in Metals.—Careful measurements of the solubility of gases in metals at high temperatures, a vessel of Meissen porcelain being used, show, according to A. Sieverts[†] and W. Krumbhaar, that nitrogen is not dissolved by the majority of metals. Aluminium reacts with nitrogen above 800°, and iron above 1200°, nitrides being formed. Carbon monoxide is dissolved by nickel, but not by copper. Oxygen is insoluble in gold. Sulphur dioxide is insoluble in solid copper, but dissolves in molten copper to an extent which is directly proportional to the temperature. The solubility of hydrogen in copper, nickel, iron, and palladium is shown in the form of curves. It is proportional to the temperature, and in all cases except that of palladium is much greater in the liquid than in the solid state. It is proportional in each case to the square root of the pressure.

The solubility of oxygen in silver is lowered by alloying with gold. That of hydrogen in copper is unchanged by alloying with silver, lowered by alloying with gold, tin, or aluminium, and raised by alloying with nickel or platinum.

Specific Heat.—Measurements of the specific heat of metals and intermetallic compounds between − 190° and + 100° by H. Schimpff[‡] show that the temperature-coefficient decreases with rise of temperature, with the two exceptions of lead and bismuth. The values given for the specific heats of the metals agree closely with those of former observers, but extend over a greater range. The specific heats of alloys differ very little from those calculated by the rule of mixtures, but alloys of magnesium have in general a smaller and those of antimony a greater specific heat than that calculated. The atomic heats of both metals and inter-

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[*] *Metallurgie*, 1909, vol. vi. pp. 769–792. Compare T. Turner and M. T. Murray, *this Journal*, vol. ii. p. 199.

[†] *Berichte der deutschen chemischen Gesellschaft*, 1910, vol. xliii. pp. 893–900.

[‡] *Zeitschrift für physikalische Chemie*, 1910, vol. lxxi. pp. 257–300.

metallic compounds increase with rising temperature, and tend to approach equality.

The same result is obtained by A. V. Saposhnikoff * from the examination of alloys of (*a*) bismuth and cadmium, which do not form compounds or solid solutions; (*b*) bismuth and antimony, which form a continuous series of solid solutions; and (*c*) zinc and antimony, which form two compounds. The specific heat is in all cases an additive property.

Thermal Analysis.—K. Friedrich † describes the advantages to be gained by the extension of the method of thermal analysis to metallurgical processes. The application of heating and cooling curves to smelting products, mattes, slags, &c., is described, as well as methods of controlling the thermal efficiency of metallurgical operations.

* *Journal of the Russian Physical and Chemical Society*, 1909, vol. xli. pp. 1708–1711.
† *Metallurgie*, 1910, vol. vii. p. 39.

ANALYSIS, TESTING, AND TEMPERATURE MEASUREMENT.

CONTENTS.

I.—*ANALYSIS.*

Arsenic Estimation in Copper.—An apparatus is described by E. Azzarello * for the rapid estimation of arsenic in arsenical copper. The metal is heated with a solution of ferric sulphate in hydrochloric acid, the vapours being passed through a washing-flask containing glass beads, maintained at 170° in an oil-bath. A special form of conical receiver, containing hydrochloric acid, is used for condensation, and the solution is then titrated in the usual manner.

Chromium Determination.—A rapid method for the determination of chromium in chrome and chrome-nickel steels is given by N. M. Randall.† In this method 1 gramme of the steel is dissolved in 25 cubic centimetres nitro-sulphuric acid. When solution is complete 15 to 20 cubic centimetres cold water is added. The solution is rotated in a beaker, and 1 gramme sodium bismuthate is added. Solution is boiled hard, the permanganate formed is rapidly decomposed and a clear violet liquid remains (manganic metaphosphate), which on further boiling converts the remainder of the chromium to chromium trioxide. The manganic metaphosphate is decomposed with $\frac{1}{2}$ cubic centimetre or more hydrochloric acid and boiling for one minute. The solution is cooled, diluted to 200 cubic centimetres. A slight excess of ferrous ammonium sulphate is added and titrated with permanganate. The acid for dissolving the steel is made as follows :—

300 cubic centimetres nitric acid, 1·42 specific gravity.
300   ,,   ,,   sulphuric acid, 1 part with 3 parts water.
300   ,,   ,,   water.
100   ,,   ,,   phosphoric acid, 85 per cent.
1·5 grammes manganese sulphate.

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* *Gazzetta*, 1909, vol. xxxix., ii. pp. 450–453.
† *Metallurgical and Chemical Engineering*, Jan. 1910, vol. viii., No. 1, pp. 17–18.

Determination of Titanium.— H. M. Ullmann * and J. W. Boyer describe the method used for the determination of titanium in argillaceous limestones, &c.   The method comprises the following steps :—

(1) Preliminary roasting.

(2) Direct fusion with potassium pyrosulphate.

(3) Solution by boiling with strong sulphuric acid (1 part H_2SO_4 to 4 parts water by volume).

(4) Calorimetric comparison by Weller's hydrogen peroxide method, with solutions of known titanium content.

Determination of Zinc.—J. M. Taylor † describes a rapid method for the estimation of zinc in the presence of iron.   The following is the method advised for the determination of zinc in liquors containing ferrous salts—5 or 10 cubic centimetres of the liquor are measured into a 600 cubic centimetre flask, 20 cubic centimetres of a saturated solution of ammonium chloride are added, together with a drop of methyl orange solution, and neutralised with $N/2$ sodium bicarbonate.   About 100 cubic centimetres of water saturated with sulphuretted hydrogen are added, and then $N/2$ sodium bicarbonate is run in slowly with constant shaking until a decided chocolate colour is given to the precipitate.   Copper, lead, and bismuth must be absent, the iron must be in the ferrous condition, the solution should measure 150 cubic centimetres after adding the sulphuretted hydrogen solution, for 0·1 to 0·3 gramme zinc.

Electro-Analysis.—E. F. Smith,‡ in a paper read before the American Electrochemical Society, October 1909, gives an account of his work in the development of modern methods of electro-analysis.   This work includes the use of rotating anodes, mercury cathodes, and also of double-compartment cells, in which the mercury acts as a bipolar electrode.

Rapid Electro-Analysis with Stationary Electrodes.—T. S. Price § and T. C. Humphreys criticise the work of J. T. Stoddart,‖ who published the results of an investigation on the rapid electro-analysis of cadmium, copper, nickel, silver, and zinc, using stationary cylindrical gauze electrodes, and depending on the heating effects and vigorous gas evolution caused by the strong currents for the agitation of the electrolyte.   The present authors have carried out determinations by similar means, and compared them with results obtained by rotating cathodes, and conclude that for rapid electrode analysis, stationary electrodes are not so reliable or satisfactory as rotating cathodes.

Volumetric Method for Copper.—The volumetric determination of copper by potassium cyanide solution is described.¶   Samples con-

* *Chemical News*, vol. c., No. 2614, pp. 323–325.

† *Journal of the Society of Chemical Industry*, vol. xxviii., No. 24, pp. 1294, 1295.

‡ *Electrochemical and Metallurgical Industry*, Dec. 1909, vol. vii., No. 12, pp. 513, 514.

§ *Journal of the Society of Chemical Industry*, March 31, 1910, vol. xxix., No. 6, pp. 307–309.

‖ *Journal of the American Chemical Society*, 1909, vol. xxxi. p. 385.

¶ *Mines and Minerals*, vol. xxx., No. 5, p. 260.

taining organic matter or much arsenic or manganese are decomposed with nitric acid and a small amount of potassium chlorate. Large amounts of organic matter may keep some iron in solution producing greenish tints. Some oxide ores and slags require a preliminary treatment with hydrofluoric acid for the complete solution of copper.

Zinc Estimation by Electrolysis.—In the electrolytic estimation of zinc, it is stated by E. B. Spear,* E. E. Wells, and B. Dyer that· the usual tendency, when the zinc is completely precipitated, is for the results to be high. In testing whether the zinc is completely precipitated, the best results are obtained with potassium ferrocyanide, which will produce a turbidity with 0·5 milligram of zinc per litre. Ammonium sulphide is not sufficiently sensitive. The high results are due to the presence of zinc oxide or hydroxide along with the precipitated metal, and not to the occlusion of gases or liquid, or to the presence of foreign metals. If the solution is made strongly alkaline, in order to prevent the precipitation of hydroxide, hydrogen is evolved, and it becomes impossible to deposit the zinc completely.

II.—*TESTING.*

Application of High-Pressure Gas to Furnace Use.—The method of using gas direct from the mains, and consuming the same in some form of Bunsen-burner, is not only wasteful, but incapable of giving constant temperatures, and A. W. Onslow † advocates the use of high-pressure gas, capable of working up to 160 inches of water-pressure. It is pointed out that high-pressure gas lighting is limited at about 60 inches pressure. Air is drawn into the burner at atmospheric pressure. A rotary exhauster and compressor draws the gas from the mains, and supplies it at any desired constant pressure to the burners. An example is given of the use of pressure gas in four laboratory furnaces, each worked at a different temperature by varying the pressure by means of reducing taps or governors ; thus one furnace kept at 2600° F. by gas pressure at 100 inches, the second furnace at 2000° F. with a pressure of 70 inches, the third furnace at 1000° F. with a pressure of 35 inches, and the fourth furnace at 650° F. with a pressure of 18 inches only. With pressure gas, quantities of about half a pound of copper have been melted in 6½ minutes. In the melting of lead in cast-iron pots, 20 inches pressure is quite sufficient ; but if it is obligatory to use 100 inches pressure, the heating must be by radiation, and not by playing directly on the iron vessel. Tempering, case-hardening, and annealing furnaces may be heated by pressure gas, and do not need large combustion chambers. In the discussion of this paper, W. R. Hodgkinson gave details of an installation of high-pressure gas in his laboratory, driven by

a 3 horse-power motor. By this means a small furnace could be kept within 2° or 3° for a whole day. T. Girtin gave some details as to the use of high-pressure gas for bullion melting.

Metallographic Apparatus.—R. Loebe * describes several new appliances for use in metallographic work. One of these is a clock giving audible signals at fixed intervals, such as every half-minute. The second is an arrangement for recording the temperature at which a wire melts, thus enabling the melting-point to be determined accurately when the quantity available is insufficient for a crucible experiment. An electrical bell-signal is employed. The other appliances are a small resistance furnace, arranged to be clamped in any position ; a clip for holding the thermo-couple ; conical carbon crucibles ; and a ring-shaped stirrer for crucibles, intended for use with a thermo-couple.

The Thoulet Solution in Ore-Testing.—H. B. Hallowell † describes the method of making the heavy Thoulet solution and various uses in which he has found it of value, such as the separation of minerals from river sand, the examination of jig tailings and middlings for zinc blende, the determination of barytes in concentrates and tailings, &c. The solution is made by dissolving four parts by weight of potassium iodide in six parts of warm water, and then adding five parts of mercuric iodide, stirring constantly. The solution is evaporated until a light crystalline scum appears, and is then cooled and filtered on heavy filter paper. The solution should be of a clear, deep amber colour, of about 3·2 specific gravity. This solution may be brought to any desired lower specific gravity by adding distilled water. The solution is used at a specific gravity of about ·03 to ·05 more than the mineral it is desired to separate, and the separations made in an ordinary separating funnel fitted with glass-stopper and cock. The sample is put into the separator, which is nearly filled with solution, well shaken to liberate air-bubbles, allowed to stand, and then the heavier material drawn off. In washing the separated minerals, all wash waters, &c., are evaporated for the recovery of the solution.

III.—*TEMPERATURE MEASUREMENT.*

Platinum Resistance Pyrometers.—C. W. Waidner ‡ and G. K. Burgess report the results of a long investigation on platinum resistance pyrometers at high temperatures, the general conclusions of which are as follows :—

Temperatures defined by the resistance thermometer of pure platinum, calibrated by Callendar's formulæ at 0°, 100°, and 444·7°, agree with the

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* *Metallurgie*, 1910, vol. vii. pp. 5–10.
† *Mines and Minerals*, April 1910, vol. xxx., No. 9, p. 531.
‡ *Bulletin of the Bureau of Standards*, 1909, vol. vi., No. 2 ; Abstract, *Metallurgical and Chemical Engineering*, Feb. 1910, vol. viii., No. 2, pp. 77–78.

temperatures on the generally accepted gas scale in the range 0° to 1100° C. to within the degree of reproducibility of the latter. Thermometers made of impure platinum and calibrated in the same way do not define the same temperature scale, the divergence increasing with the impurity of the metal.

By calibrating thermometers of impure platinum at a fourth temperature, such as the freezing-point of silver, then the scale so defined may be brought into very close agreement with pure platinum thermometers.

The palladium theremometer, calibrated by the Callendar method, gives temperatures agreeing to 1° with the scale of the platinum thermometer up to 600°; it requires a fourth degree equation to express its resistance-temperature relation from 0° to 100°.

Thermo-couples of platinum—platinum-10% rhodium, and platinum—platinum-10% iridium, calibrated at three temperatures, define a temperature scale in the interval 200° to 1100°, which is in agreement with the platinum-resistance scale at intermediate temperatures to within 0·3°. The authors conclude that when platinum thermometers are used at high temperatures, they undergo gradual changes which necessitate frequent calibration in work of high precision. The use of thermo-couples for work above the freezing-point of silver is therefore much less laborious. These changes in thermometric constants are greatly reduced, but not completely eliminated, by annealing the thermometers for several hours at a temperature higher than that at which they are subsequently to be used.

For thermometers of pure platinum, the changes in their constants after annealing are much less than for impure platinum thermometers; these changes are least for pure platinum wires of large diameter and suspended free from strains. For impure platinum wire the effect of high temperatures is such as if the wire became purer, possibly because of the evaporation of impurities—for example, iridium. If the platinum is pure, the slight changes indicate a contamination of the wire and the effect of strains. As to calibration temperatures, the authors state that the freezing-points of pure metals are the most satisfactory, being superior to boiling-points in constancy, ease of manipulation, and reproducibility.

Temperature Conversion Table.—A very convenient Centigrade and Fahrenheit temperature conversion table is reproduced.* This was devised by L. Waldo, and is based on an arrangement well known from logarithmic tables.

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* *Metallurgical and Chemical Engineering*, March 1910, vol. viii., No. 3, p. 123.

STATISTICS.

Copper.—The statistical position and future of copper is discussed by J. Douglas.* The world's production of pig iron and pig copper are compared for the last nine years. In 1908, 47,508,692 tons of pig iron were produced, showing a decrease of 20·44 per cent. on 1907 ; and in the same year 750,067 tons of pig copper were produced, showing an increase of 5·46 per cent. on 1907.

Gold and Silver in U.S.A.—According to the joint report of the United States Geological Survey and the Bureau of the Mint † the production of gold in that country during 1908 amounted to 4,574,340 fine ounces, which represents a value of $94,560,000. The figures show an increase of 199,513 fine ounces over the preceding year. The production of silver was 52,440,800 fine ounces, and was valued at $28,050,600, this being a shrinkage of 4,073,900 fine ounces from the 1907 figures.

Metal Production in Colorado.—The metal production in Colorado for the year 1909 was valued at $42,575,878.‡ It was distributed as follows :—

Gold, 1,303,713 oz. at $20·67	$29,949,803
Silver, 11,614,500 oz. at 51·5 cents . . .	5,981,461
Lead, 34,023 tons at $85·60	2,912,289
Copper, 12,829,561 lbs. at 13 cents . . .	1,667,843
Spelter, 24,262 tons at $107·20 . . .	2,600,920
Chemicals from Colorado ores	1,701,562
Tungsten, 1100 tons at $360	396,000
Vanadium, 120,000 lbs. at $2·50	300,000
Uranium, Gilpin County	35,000
Manganiferous iron silver ores	15,000
Pyritic iron silver ores	16,000

* *Engineering Magazine*, Dec. 1909, vol. xxxviii., No. 3, pp. 325–329.
† *Metallurgical and Chemical Engineering*, March 1910, vol. viii., No. 3, pp. 164–165.
‡ *Ibid.*, p. 163.

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EDITORIAL NOTE.

It is regretted that Section II. of the Journal is not as complete as it was intended that it should be. A package containing a large number of Abstracts was unfortunately lost in the post. It is hoped, however, to publish most of these Abstracts in Vol. IV., so that our record of papers "relating to the non-ferrous metals and the industries connected therewith" will not be permanently impaired.

SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION, AND LIST OF MEMBERS.

CONTENTS

The Companies (Consolidation) Act, 1908

Memorandum of Association

OF

THE INSTITUTE OF METALS

1. The name of the Association is THE INSTITUTE OF METALS.

2. The Registered Office of the Association will be situate in England.

3. The objects for which the Association is established are :—

(*a*) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between of the first part, of the second part, and the Association of the third part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.

(*b*) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the

progress of inventions likely to be useful to the members of the Association and to the community at large.

(*c*) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.

(*d*) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.

(*e*) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.

(*f*) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sub-let, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.

(*g*) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.

(*h*) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon any of the property of the Association (both present and future), and to redeem and pay off any such securities.

(*i*) To undertake and execute any trusts, the undertaking whereof may seem desirable.

(*k*) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.

(*l*) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.

(*m*) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.

(*n*) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whencesoever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council

or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Association. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges, and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having

objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members.   Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

The Companies (Consolidation) Act, 1908

Articles of Association

OF

THE INSTITUTE OF METALS

Section I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association.

U

4. Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

Honorary Members.—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (*a*) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (*b*) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (*a*) Students of Metallurgy; or (*b*) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

Section II.—ELECTION OF MEMBERS.

6. Save as hereinbefore provided, applications for membership shall be in writing in the form following marked " A,"

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned,   , being of the required age and desirous of becoming a   Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full...

Address..

Business or Profession...

Qualifications..

Signature..

Dated this   day of   , 19   .

.... ⎫
.... ⎬ Signatures
.... ⎭ of three
Members.

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to

him of his election, as provided in the next clause hereof, his election shall be void.

8. Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form following marked " B."

FORM B.

Sir,—I beg to inform you that on the   you were elected a   Member of the Institute of Metals, subject to the payment by you of an entrance fee of £   , and of your first annual subscription of £   . These must be paid to me on or before the   day of   19 , otherwise your election will become void.

I am, Sir, your obedient Servant,

....Secretary.

9. In the case of non-election, no mention thereof shall be made in the minutes.

Section III.—COUNCIL AND MODE OF ELECTION

10. The affairs of the Association shall be managed and conducted by a Council, which shall consist of a President, Past-Presidents, six Vice-Presidents, fifteen Members of Council, an Hon. Secretary or Hon. Secretaries, and an Hon. Treasurer. All members who have filled the office of President shall be, so long as they remain members of the Association, *ex officio* additional members of the Council under the title of Past-Presidents. The first members of the Council shall be the following:—President, Sir Gerard Muntz, Bart.; Vice-Presidents, J. D. Bonner, Prof. H. C. H. Carpenter, Prof. W. Gowland, Prof. A. K. Huntington, Engineer Vice-Admiral H. J. Oram, Sir Henry A. Wiggin, Bart. Ordinary Members of Council, T. A. Bayliss, G. A. Boeddicker, Clive Cookson, J. Corfield, R. Kaye Gray, Summers Hunter, Dr. R. S. Hutton, E. Mills, J. T. Milton, G. H. Nisbett, E. Ristori, A. E. Seaton, Cecil H. Wilson, Prof. T. Turner (Hon. Treasurer), W. H. Johnson (Hon. Secretary).

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of " Members of the Council " for " Directors " wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (*a*) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other

than one of those nominated by the Council. A list of candidates so nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the Scrutineers. The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council. And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

Section IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting. In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid. All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary

Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals.*

The Council shall have power to appoint a paid Secretary or Secretaries, and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

Section V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be 10 members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered

address within the United Kingdom) have not supplied to the Association an address within the United Kingdom for the giving of notices to them. No other persons shall be entitled to receive notices of General Meetings, but the Association may, but shall not be bound to give notice of General Meetings to members not entitled thereto in such manner as in the opinion of the Council may be practicable and convenient.

Section VI.—SUBSCRIPTIONS

28. The subscription of each ordinary member shall be two guineas per annum, and of each student member one guinea per annum. Ordinary members shall pay an entrance fee of two guineas each, and students an entrance fee of one guinea each. Provided that no entrance fee shall be required from any person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the Incorporation of this Association, and who had paid an entrance fee to the said Society. No entrance fee or subscription shall be payable in the case of Honorary members.

29. Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer, and for this purpose any subscription paid to the unincorporated Society for the period of July 1st, 1909, to June 30th, 1910, by any person who becomes a member of this Association shall go and be in satisfaction of any payment due in respect of membership of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice in the Form following marked "C" shall be given to such member, and if such subscription remains

unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

Sir,—I am directed to inform you that your subscription to the Institute of Metals, due   , and amounting to £   , is in arrear, and that if the same be not paid to me on or before the   day of   , 19   , your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member, after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

Section VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act 1908 as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

Section VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following :—

  (*a*) Communications made by members, students, or others.
  (*b*) Abstracts of papers appearing elsewhere.
  (*c*) Original papers appearing elsewhere.
  (*d*) Advertisements approved by the Council.

Every member shall be entitled to receive   copies of the Journal, delivered, post free, to his registered address.

Section IX.—COMMUNICATIONS

34. All communications shall be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

Section X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

Section XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

Section XII.—INDEMNITY

38. Every member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

Names, Addresses, and Descriptions of Subscribers

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[Though the foregoing Memorandum and Articles of Association have been approved by the Board of Trade, it has not been possible to insert the "Names, Addresses, and Descriptions of Subscribers" therein, as the necessary signatures and other particulars could not be appended until some time after this volume of the *Journal* had gone to press. These particulars, together with the official Certificate of Incorporation, will be given in a subsequent volume of the *Journal*. —Ed.]

LIST OF MEMBERS

Members of Council are indicated by italics.
Original Members' names are undated.
† *Denotes Contributor of Paper.*

Elected
Member.

HONORARY MEMBER

MATTHEY, GEORGE, F.R.S.,
    Cheyne House, Chelsea Embankment, S.W.

ORDINARY MEMBERS

ADAMS, GEORGE,
    Strathblane, Forest Glade, Leytonstone, Essex.
ADAMS, GEORGE NORTH,
    Mars Iron Works, Wolverhampton.
ADAMSON, JOSEPH,
    Oaklands, Hyde, Cheshire.
AINSWORTH, GEORGE,
    The Hall, Consett, Durham.

1910   ALLAN, ANDREW, Jun.
    A. Allan & Son, 486 Greenwich Street, New
        York, U.S.A.
ALLAN, JAMES M'NEAL,
    St. Peter's Works, Newcastle-on-Tyne.
ALLELY, WILLIAM SMITH,
    3 Regent Street, Birmingham.
ALLEN, JOHN HILL,
    Spring Hill, Birmingham.
ALLEN, WILLIAM HENRY,
    Queen's Engineering Works, Bedford.
ALLMAN, WILLIAM,
    Cope, Allman & Co., Ltd., Icknield Square,
        Birmingham.
†   ANDREW, JOHN HAROLD, M.Sc.,
    Victoria University, Manchester.
APPLETON, JOSEPH,
    Appleton & Howard, 12 Salisbury Street, St. Helens.
ARCHBUTT, LEONARD,
    4 Madeley Street, Derby.

ASHOFF, WILHELM,
>   Basse Selve, Altena, Westphalia, Germany.

ASTON, HENRY HOLLIS,
>   Tennal House, Harborne, Birmingham.

BAILEY, GEORGE HERBERT, D.Sc., Ph.D.,
>   Edenmor, Kinlochleven, Argyll, N.B.

BAIN, JAMES,
>   Lealholme, Liverpool Road, Great Crosby, Liverpool.

BAINBRIDGE, JOHN WILLIAM,
>   2 Fen Court, Fenchurch Street, E.C.

BAKER, THOMAS, M.Sc.,
>   "Westfield," Coldstream Street, Llanelly, South Wales.

BAMFORD, CHARLES CLIFFORD,
>   Winfields Rolling Mills, Cambridge Street, Birmingham.

† BANNISTER, CHARLES OLDEN, Assoc.R.S.M.,
>   60 West Side, Clapham Common, S.W.

BARCLAY, WILLIAM ROBB,
>   50 Upper Albert Road, Meersbrook, Sheffield.

BARKER, JOHN HENRY,
>   Birmingham Metal and Munitions Company, Ltd., Adderley Park Mills, Birmingham.

BARNARD, ALFRED HENRY,
>   H. B. Barnard & Sons, 59/60 Gracechurch Street, E.C.

BARNARD, GEORGE,
>   Callendar's Cable and Construction Company, Ltd., Cambridge Street, Birmingham.

BARNES, ALFRED,
>   Box 556, Pretoria, Transvaal.

BARR, Professor ARCHIBALD, D.Sc.,
>   James Watt Engineering Laboratories, The University, Glasgow.

BARWELL, CHARLES H.,
>   Barwells Ltd., Pickford Street, Birmingham.

1910   BASSETT, WILLIAM H.,
>   American Brass Co., Waterbury, Conn., U.S.A.

BATE, WILLIAM,
>   8 and 9 Goodall Street, Walsall.

BATES, Major DARWIN,
>   The Orchard, Huyton, Liverpool.

BATY, ERNEST JOCELYN, B.Sc.,
>   "Nunclose," Princes Avenue, West Kirby, Cheshire.

BAWDEN, FREDERICK,
    Garston Copper Works, Liverpool.
BAYLAY, WILLOUGHBY LAKE,
    28 Hardy Road, Blackheath, S.E.
BAYLISS, THOMAS ABRAHAM,
    King's Norton Metal Co., Ltd., King's Norton, Bir-
        mingham.
BAYLISS, THOMAS RICHARD,
    Belmont, Northfield, Birmingham.
BEAN, G.,
    Allen, Everitt & Sons, Ltd., Kingston Metal
        Works, Smethwick, Birmingham.
BEARE, Professor HUDSON, B.A., B.Sc.,
    Engineering Laboratories, The University, Edin-
        burgh.
BECKER, PITT,
    18/19 Fenchurch Street, E.C.
BEDFORD, CHARLES YVONER RILAND,
    H. H. Vivian & Co., Ltd., Icknield, Port Road,
        Birmingham.
BEDSON, JOSEPH PHILLIPS,
    137 Lapwing Lane, Didsbury, Manchester.
BEER, LUDWIG,
    Beer, Sondheimer & Co., Frankfurt-am-Main.

1910 BEILBY, GEORGE THOMAS, LL.D., F.R.S.,
    11 University Gardens, Glasgow.
BELL, Sir HUGH, Bart.,
    Rounton Grange, Northallerton.
BELL, THOMAS,
    J. Brown & Co., Ltd., Clydebank, Dumbartonshire.
† BENGOUGH, GUY D., M.A.,
    The University, Liverpool.
BENN, ERNEST JOHN PICKSTONE, Editor, *The Hardware
        Trade Journal,* 31 Christopher Street, E.C.
BENN, Sir JOHN WILLIAMS, *The Hardware Trade Journal,*
    31 Christopher Street, E.C.
BENSEL, ARLINGTON,
    Driver Harris Wire Company, Harrison (Newark),
        New Jersey, U.S.A.
BENTON, ARTHUR,
    Benton Bros., Rodley Foundry, Sheffield.
BEVIS, HENRY,
    45 Basinghall Street, E.C.
BIBBY, JOHN HARTLEY,
    John Bibby & Co. (Garston), Ltd., Garston Copper
        Works, Liverpool.
BILES, Professor JOHN HARVARD, LL.D.,
    10 University Gardens, Glasgow.

BILLINGTON, CHARLES,
" Heimath," Longport, Staffordshire.

BIRCH, HARRY,
J. Birch & Sons, Ltd., Upper Brook Street, Walsall.

BLAIKLEY, ARTHUR,
181 Belsize Road, South Hampstead, N.W.

BLOOMER, FREDERICK JOHN,
Penpont, Clydach, S.O., Glam.

BLOUNT, BERTRAM,
76/78 York Street, Westminster, S.W.

BOEDDICKER, GUSTAV ADOLF,
H. Wiggin & Co., Ltd., Wiggin Street Works, Bir-
mingham.

BOLTON, THOMAS,
T. Bolton & Sons, Ltd., 88 Bishopsgate Street
Within, E.C.

BONNER, JOHN DICK (Vice-President),
21 Cadogan Gardens, S.W.

BOOTH, CUTHBERT RAYNER,
Tudor House, Michleton, Gloucester.

BOW, WILLIAM,
Bow, McLachlan & Co., Thistle Works, Paisley.

BRABY, CYRUS,
F. Braby & Co., Ltd., 110 Cannon Street, E.C.

BRAY, DAVID,
" Lynwood," Barr Common, Walsall.

BRECKNELL, HENRY EDWIN FRANK,
330 Fishponds Road, Eastville, Bristol.

BRENTNALL, JOHN, M.Sc.,
c/o Messrs. G. Clark & Sons, Hull.

BRIDGES, FREDERICK WILLIAM,
Ironmongers' Chronicle and The Hardwareman, 119
Finsbury Pavement, E.C.

BROADFOOT, JAMES,
Lymhurst, South Brae Drive, Glasgow.

BROADFOOT, WILLIAM RITCHIE,
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